2017

METHODS , SYSTEMS , AND DEVICES RELATING TO SURGICAL END EFFECTORS

Shane M. Farritor
University of Nebraska-Lincoln, sfarritor@unl.edu

Tom Fredrick
Omaha, NE

Joe Bartels
Lincoln, NE

US009757187B2

(12) **United States Patent**
Farritor et al.

(10) **Patent No.: US 9,757,187 B2**
(45) **Date of Patent: *Sep. 12, 2017**

(54) **METHODS, SYSTEMS, AND DEVICES RELATING TO SURGICAL END EFFECTORS**

(71) Applicant: **Board Of Regents of the University of Nebraska**, Lincoln, NE (US)

(72) Inventors: **Shane Farritor**, Lincoln, NE (US); **Tom Fredrick**, Omaha, NE (US); **Joe Bartels**, Lincoln, NE (US)

(73) Assignee: **Board of Regents of the University of Nebraska**, Lincoln, NE (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **14/745,587**

(22) Filed: **Jun. 22, 2015**

(65) **Prior Publication Data**

US 2015/0289926 A1 Oct. 15, 2015

Related U.S. Application Data

(63) Continuation of application No. 13/493,725, filed on Jun. 11, 2012, now Pat. No. 9,060,781.

(51) **Int. Cl.**
A61B 18/18 (2006.01)
A61B 18/14 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***A61B 18/1445*** (2013.01); *A61B 34/30* (2016.02); *A61B 2018/0063* (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC A61B 19/2203; A61B 18/1445; A61B 2018/0063
(Continued)

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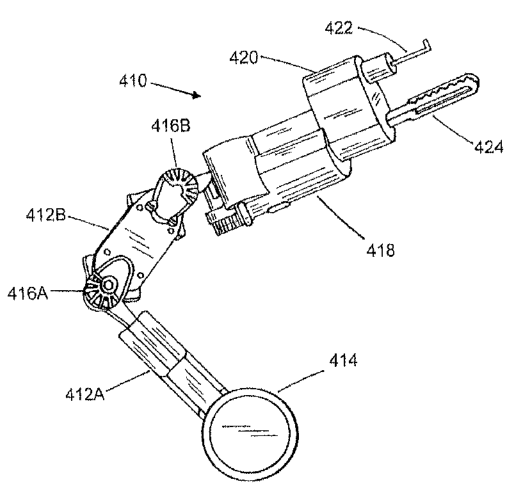
Primary Examiner — Carl H Layno
Assistant Examiner — Jon Eric C Morales
(74) *Attorney, Agent, or Firm* — Davis, Brown, Koehn, Shors & Roberts, P.C.; Sean D. Solberg

(57) **ABSTRACT**

The embodiments disclosed herein relate to various medical device components, including components that can be incorporated into robotic and/or in vivo medical devices, and more specifically including end effectors that can be incorporated into such devices. Certain end effector embodiments include various vessel cautery devices that have rotational movement as well as cautery and cutting functions while maintaining a relatively compact structure. Other end effector embodiments include various end effector devices that have more than one end effector.

19 Claims, 23 Drawing Sheets



(51) **Int. Cl.**
A61B 19/00 (2006.01)
A61B 18/00 (2006.01)
A61B 34/30 (2016.01)

(52) **U.S. Cl.**
CPC *A61B 2018/00345* (2013.01); *A61B 2018/00595* (2013.01); *A61B 2018/1455* (2013.01); *A61B 2034/301* (2016.02)

(58) **Field of Classification Search**
USPC 606/33, 130, 170
See application file for complete search history.

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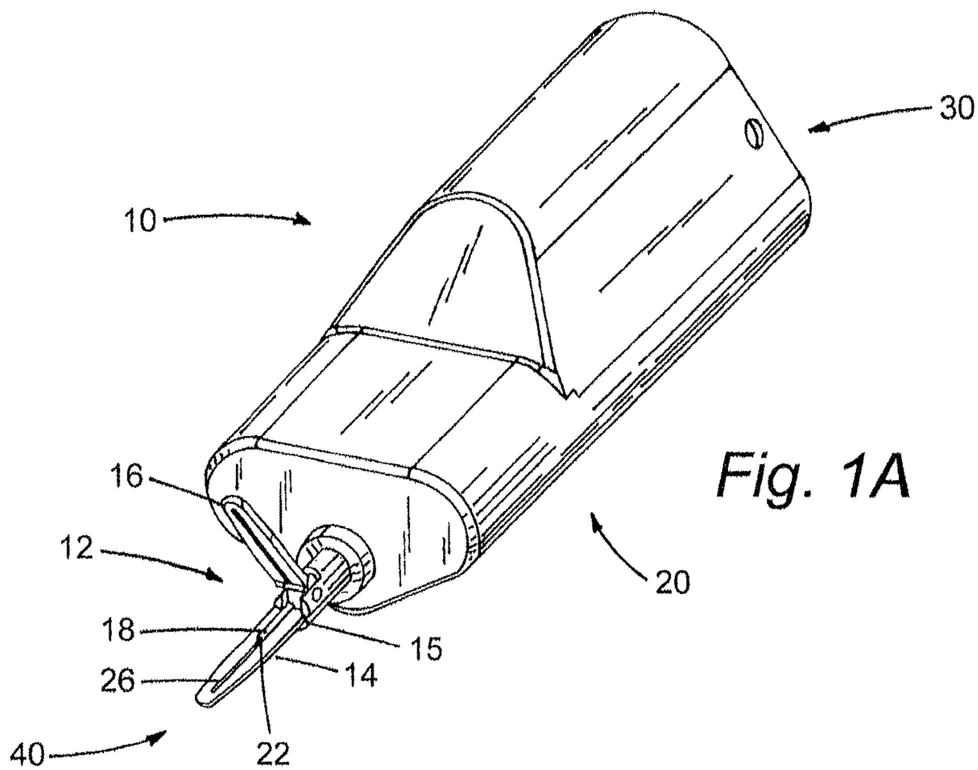


Fig. 1A

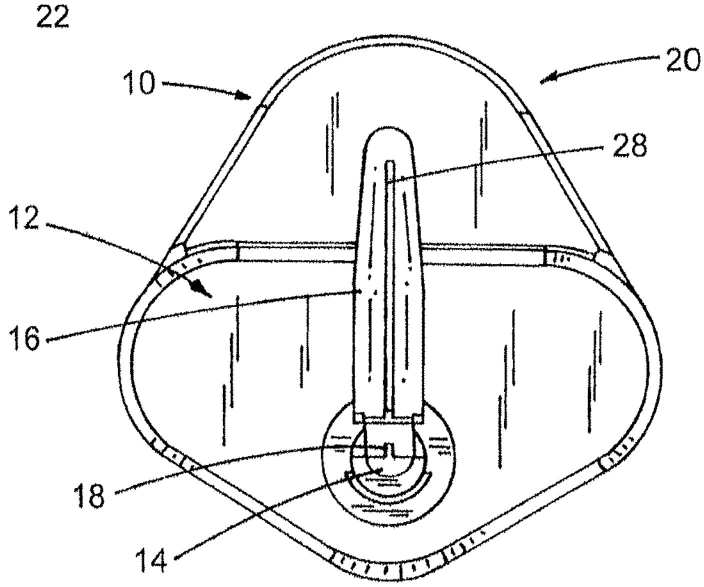


Fig. 1B

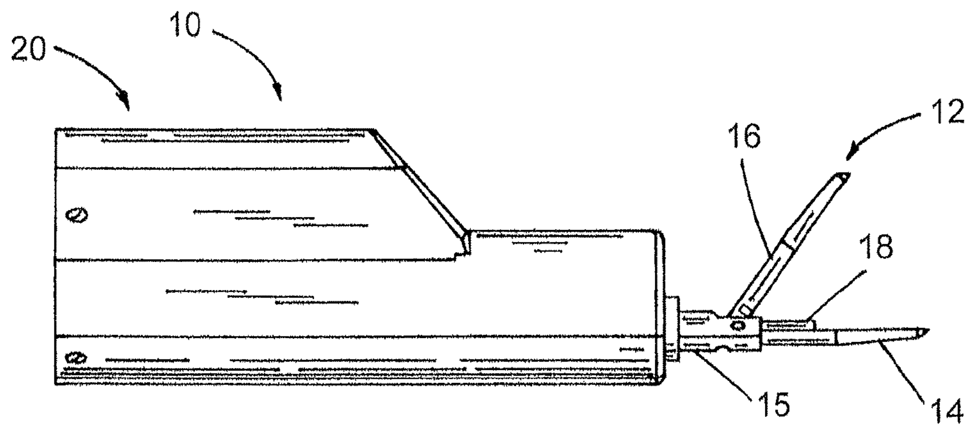


Fig. 1C

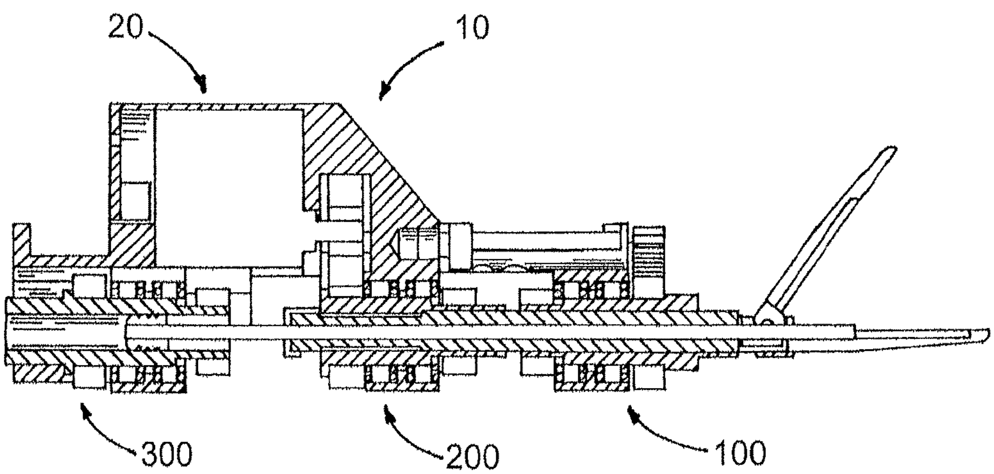
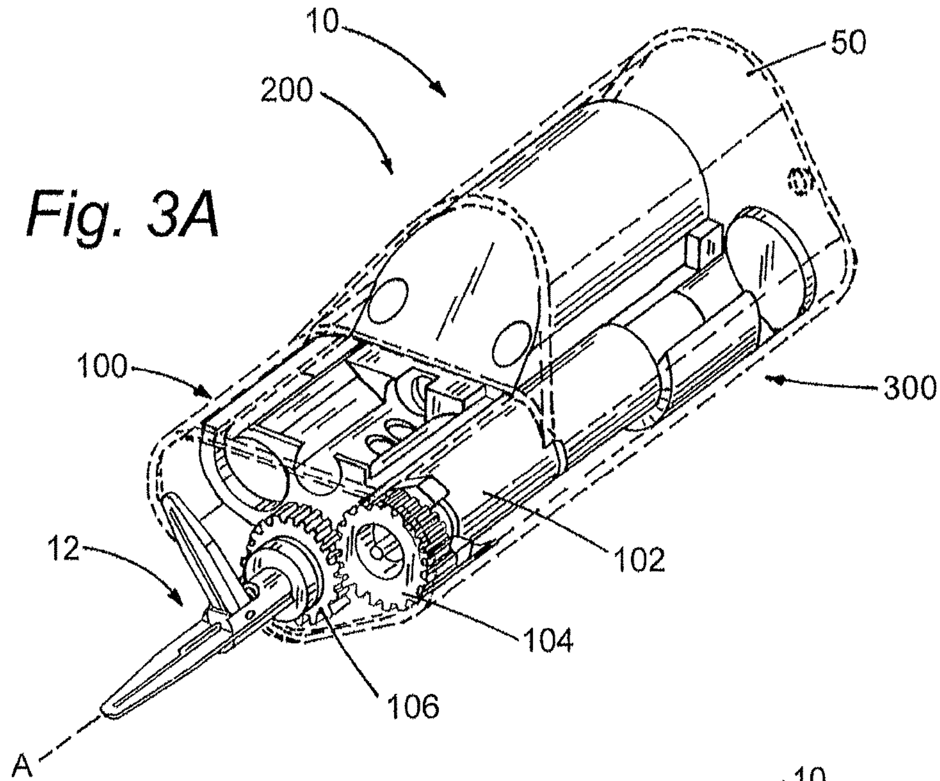


Fig. 2

Fig. 3A



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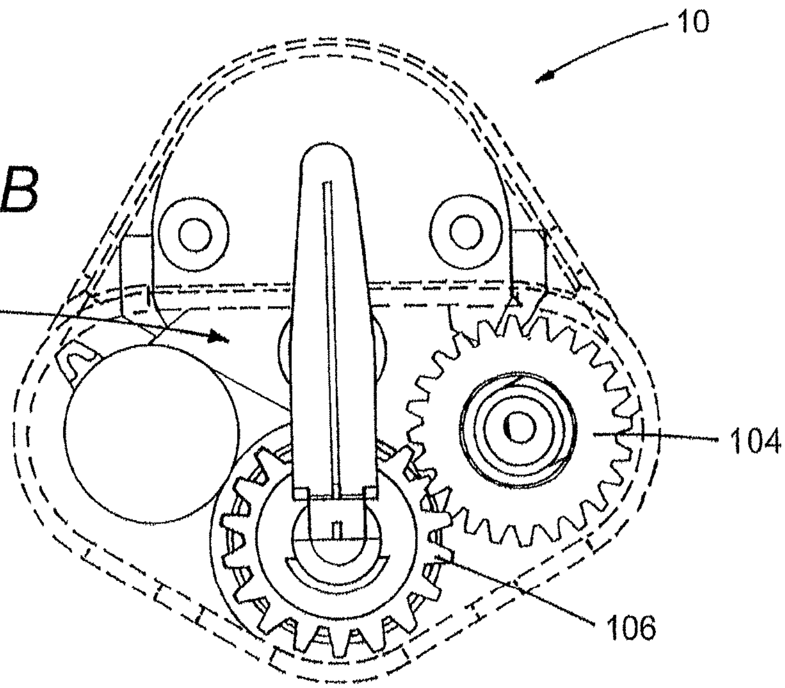

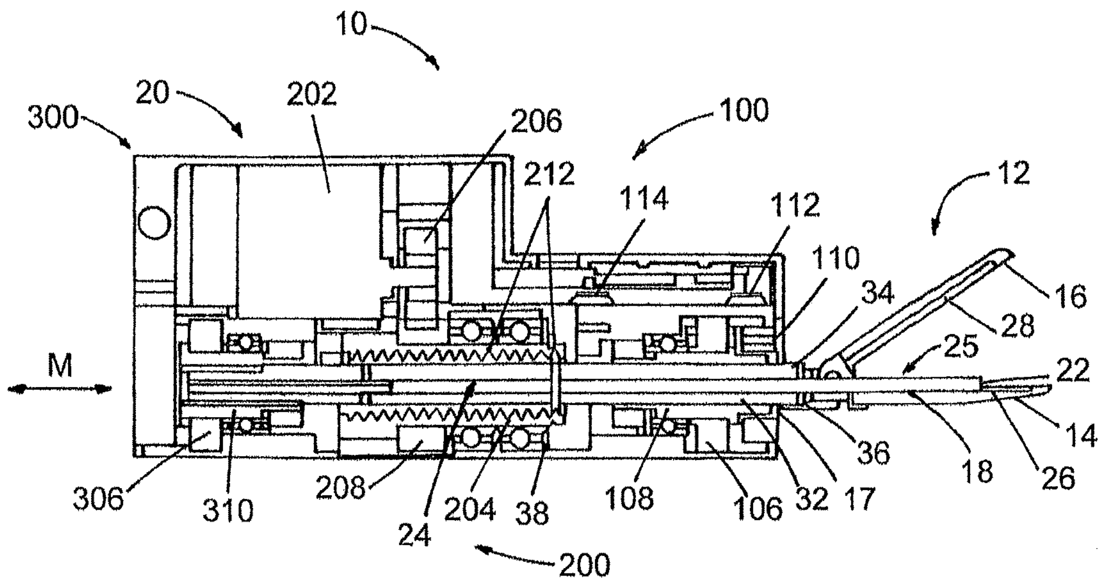
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Fig. 4

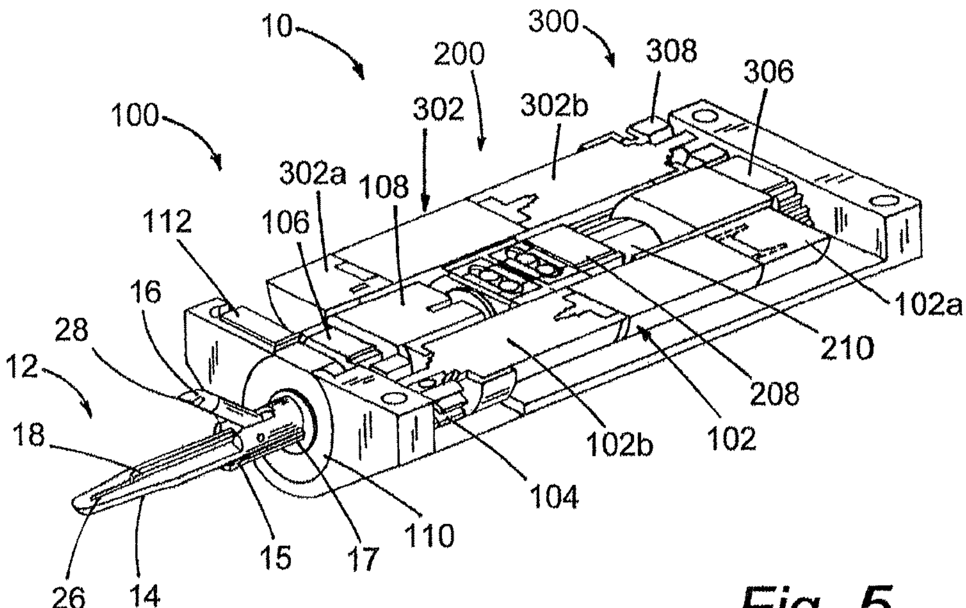
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Fig. 5

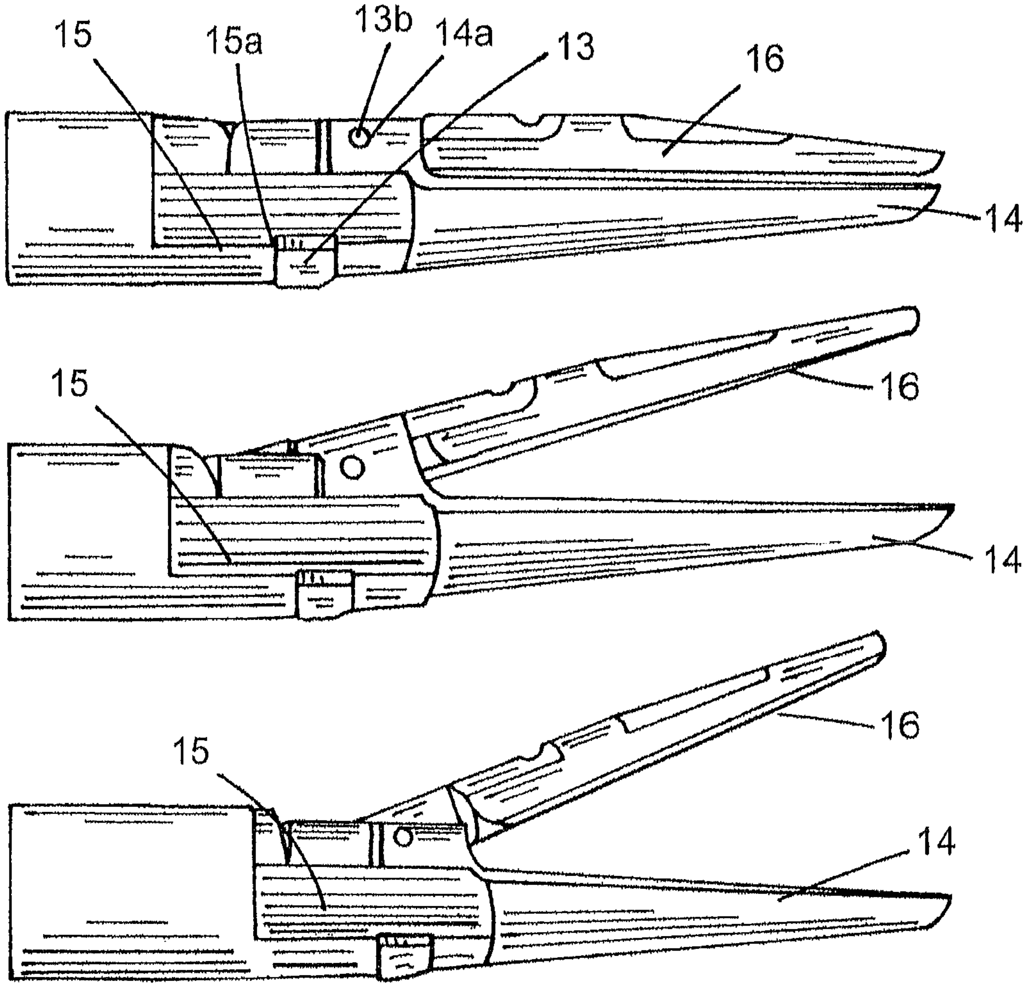

Fig. 6

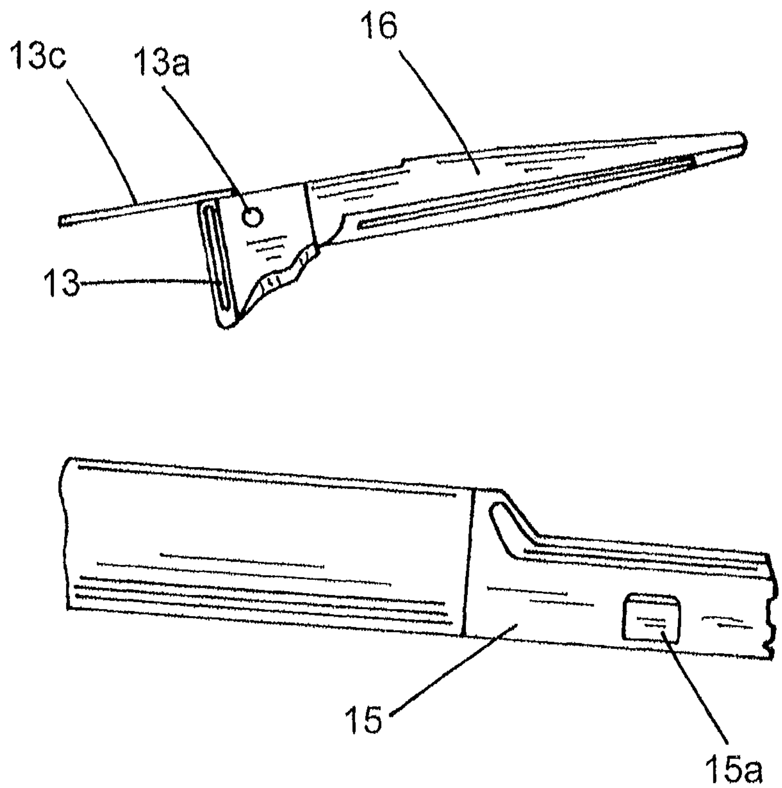

Fig. 7

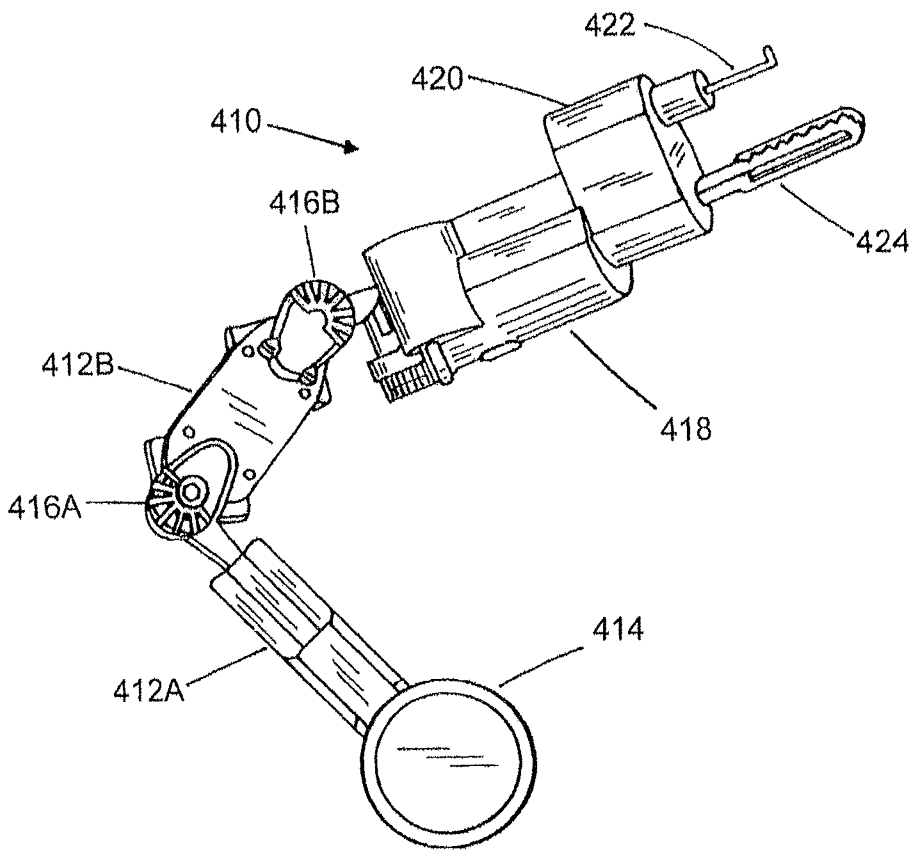
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Fig. 8A

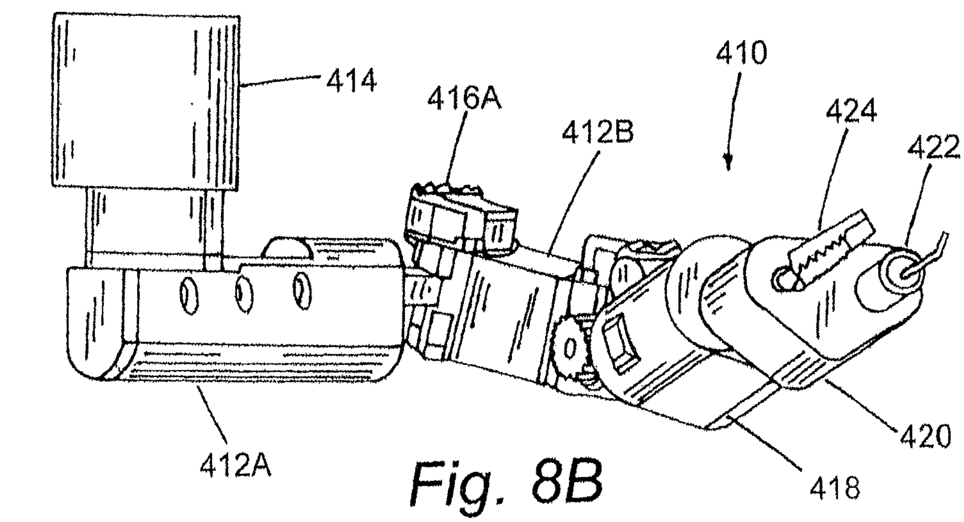
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Fig. 8B

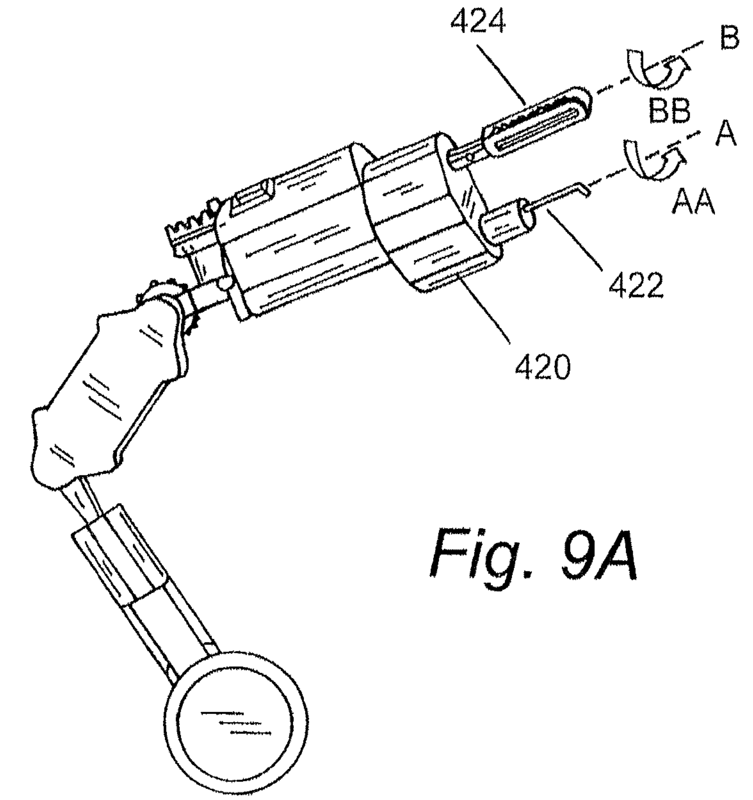


Fig. 9A

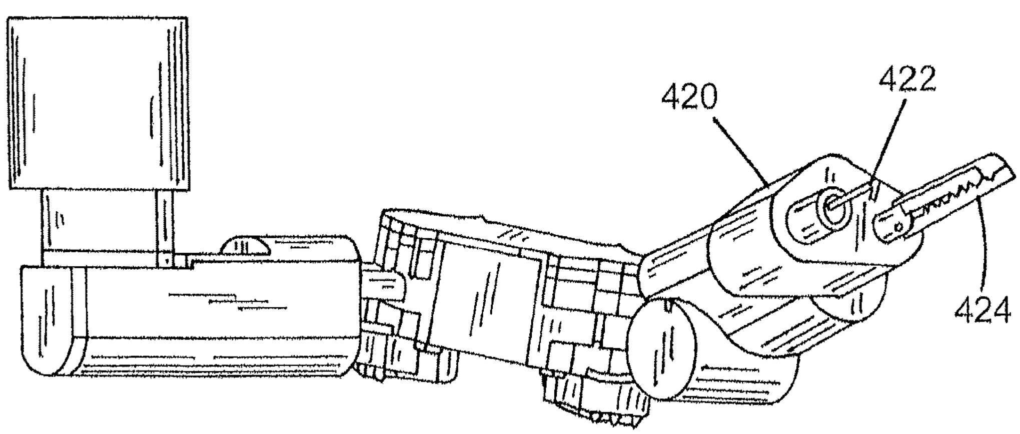


Fig. 9B

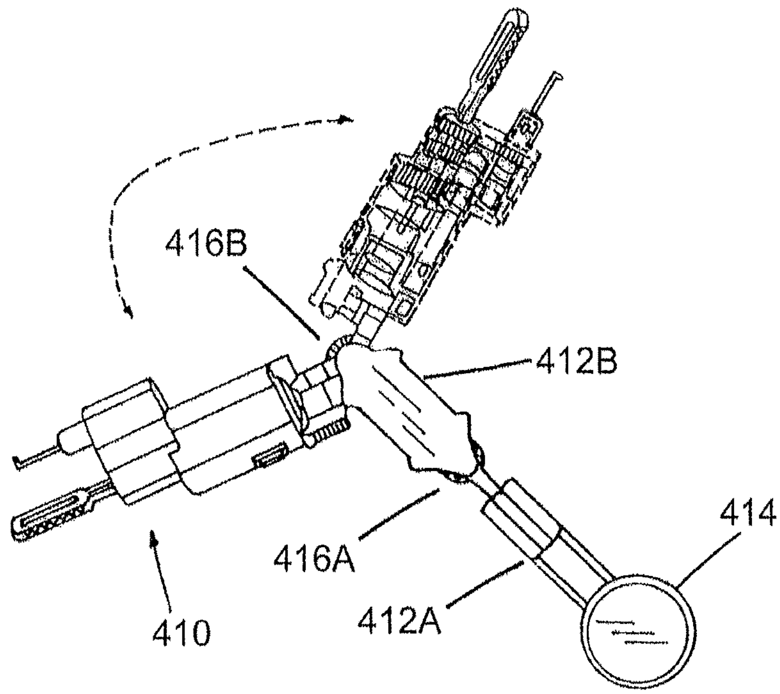


Fig. 10A

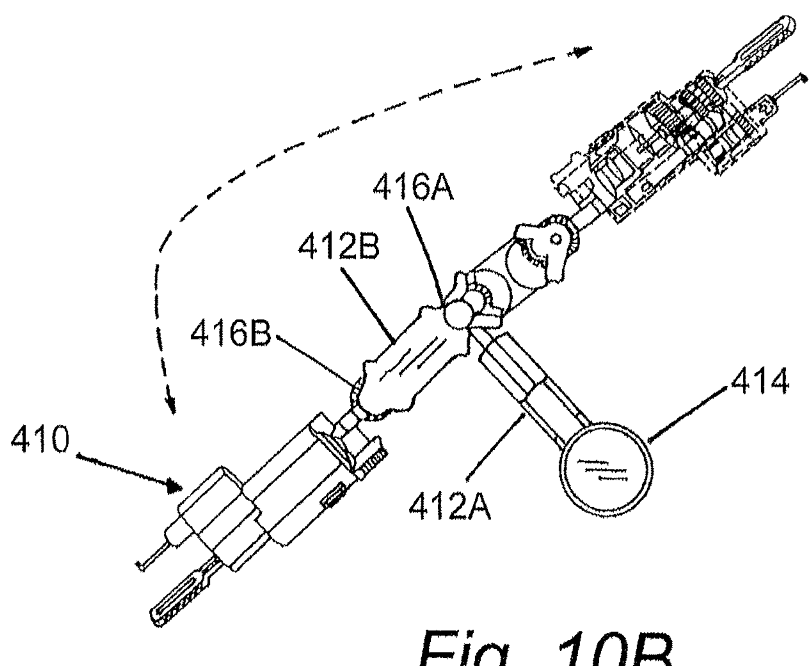
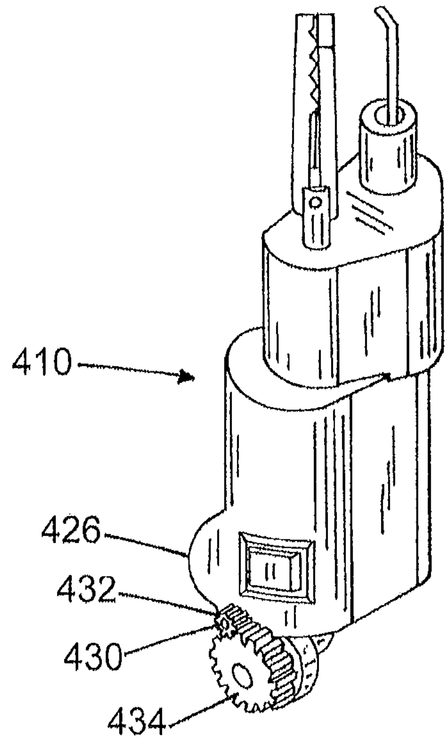


Fig. 10B



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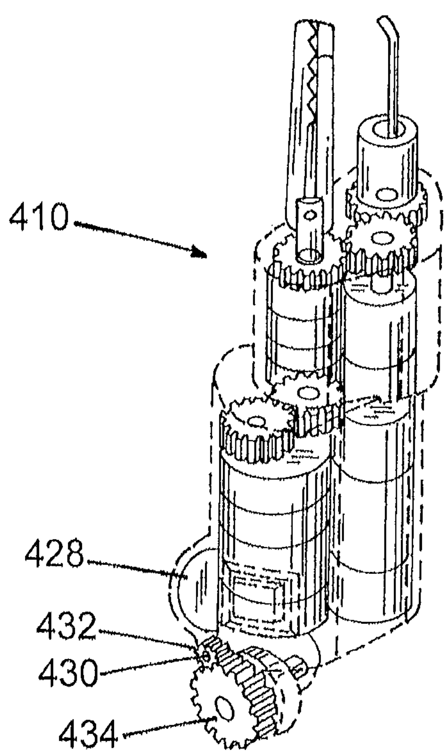

Fig. 11B

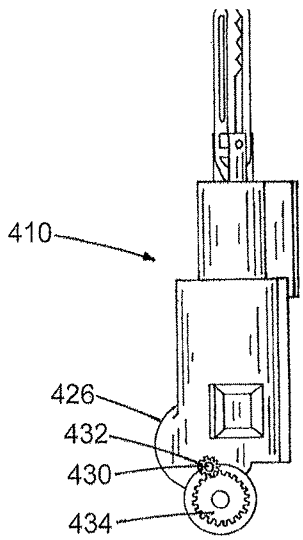

Fig. 12A

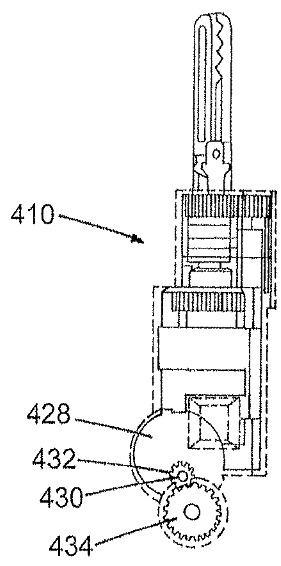

Fig. 12B

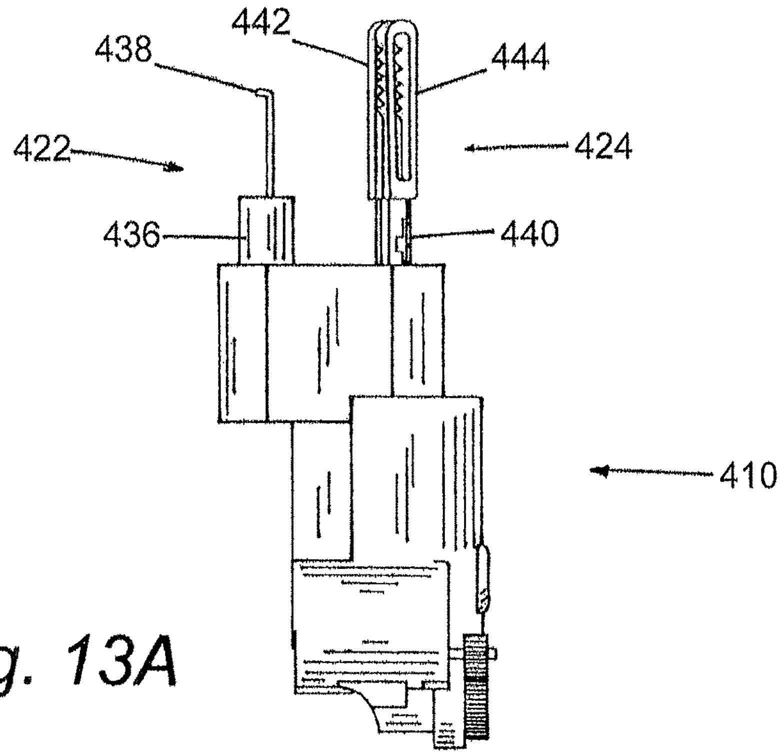

Fig. 13A

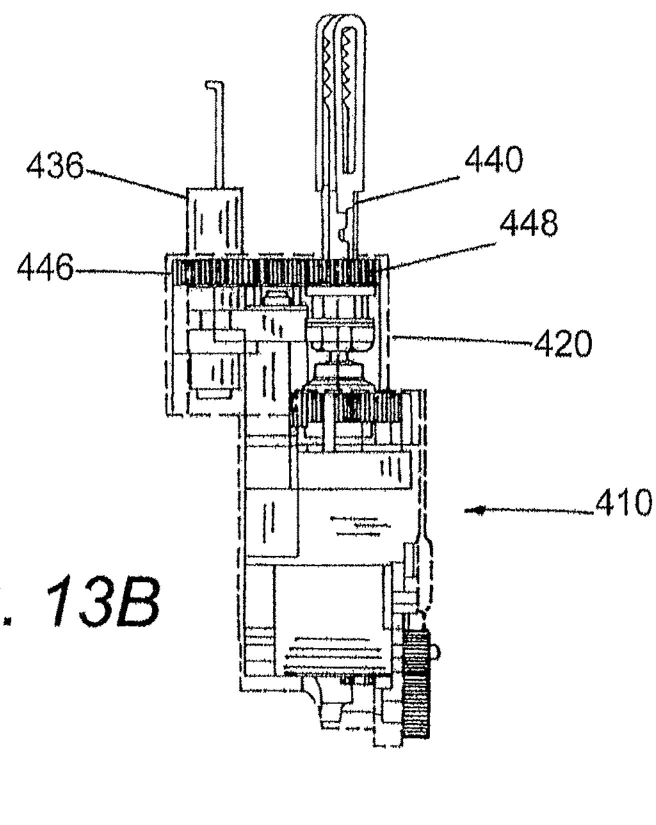

Fig. 13B

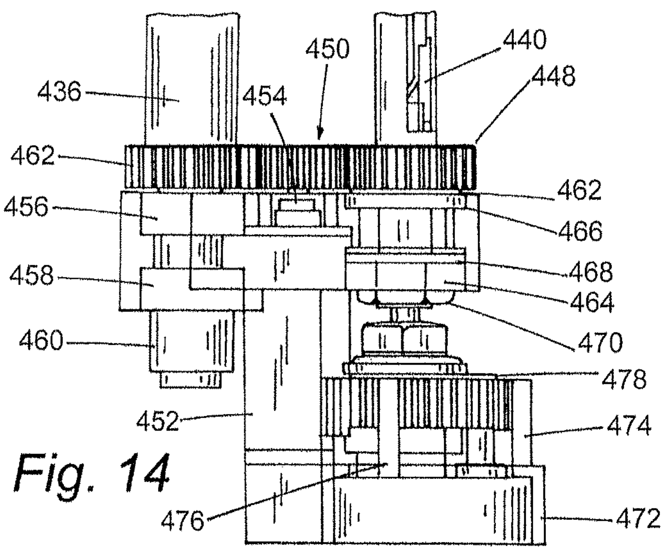
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Fig. 14

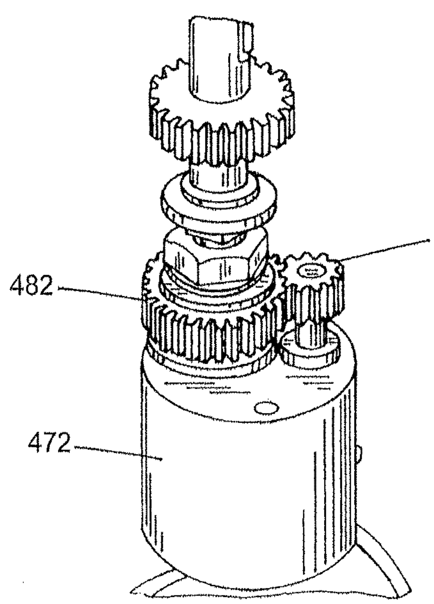
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Fig. 15

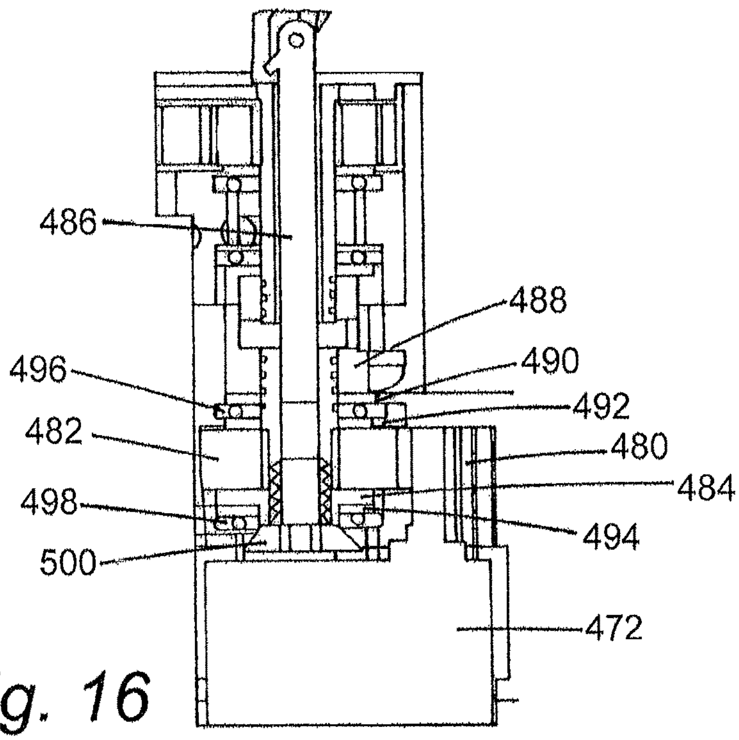
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Fig. 16

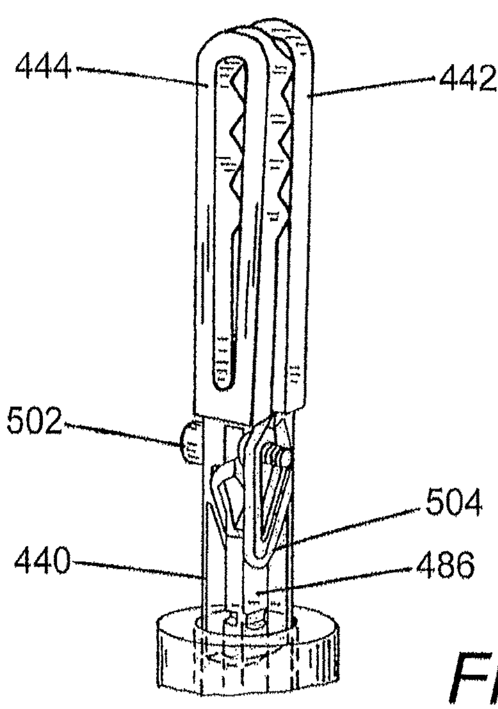
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Fig. 17

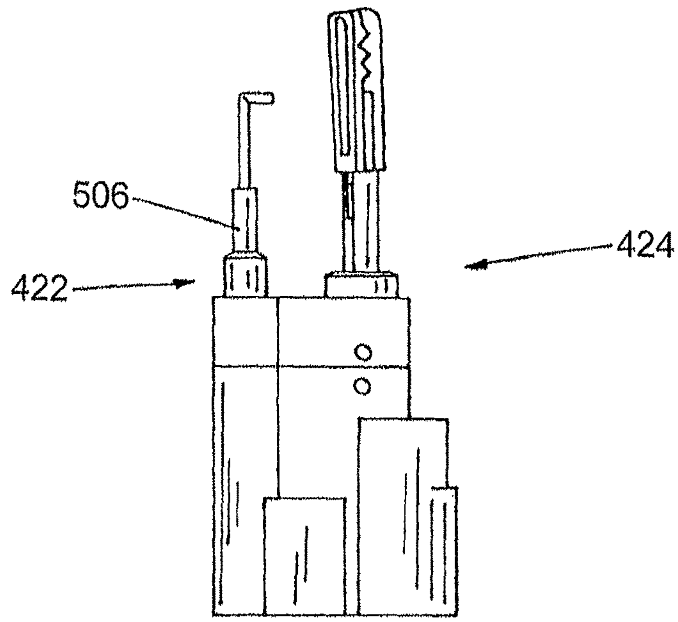

Fig. 18

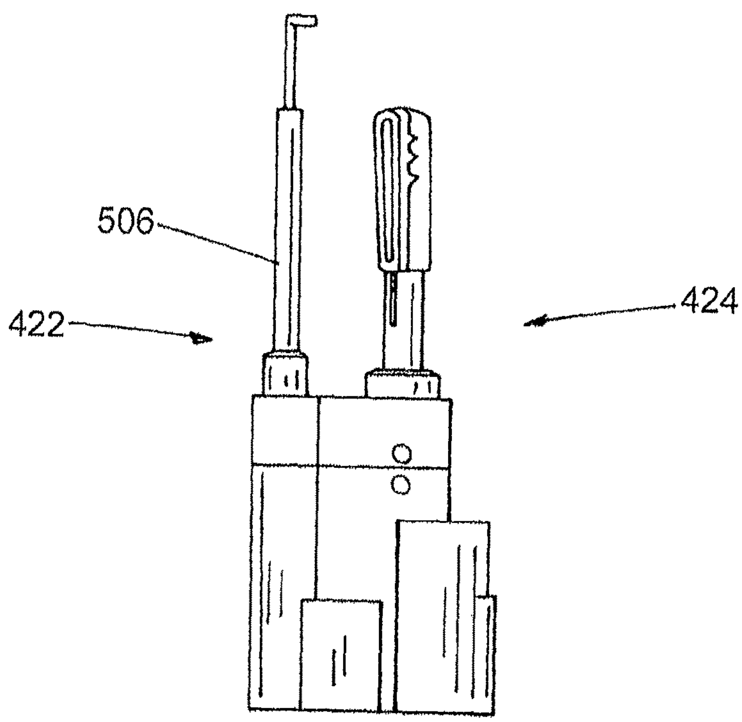

Fig. 19

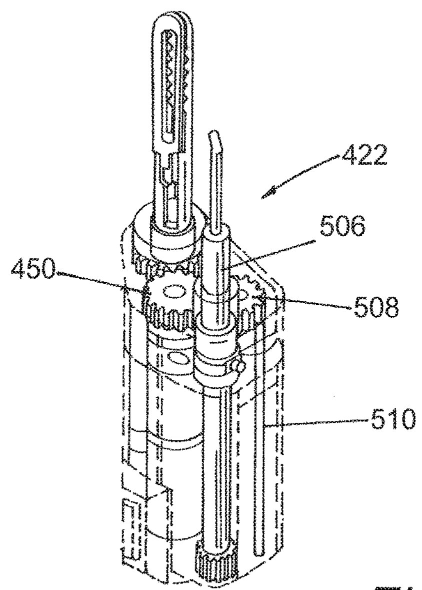

Fig. 20

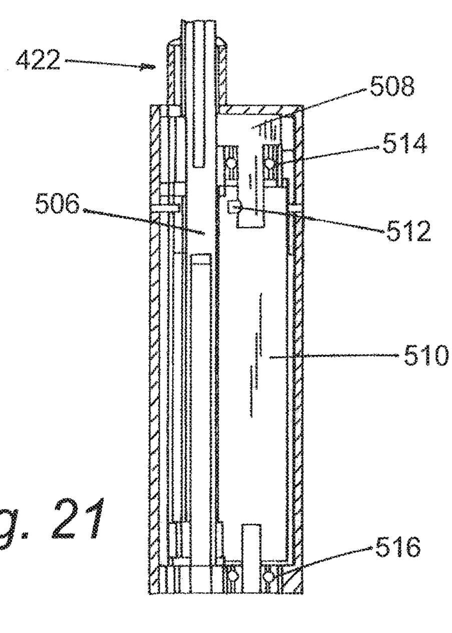

Fig. 21

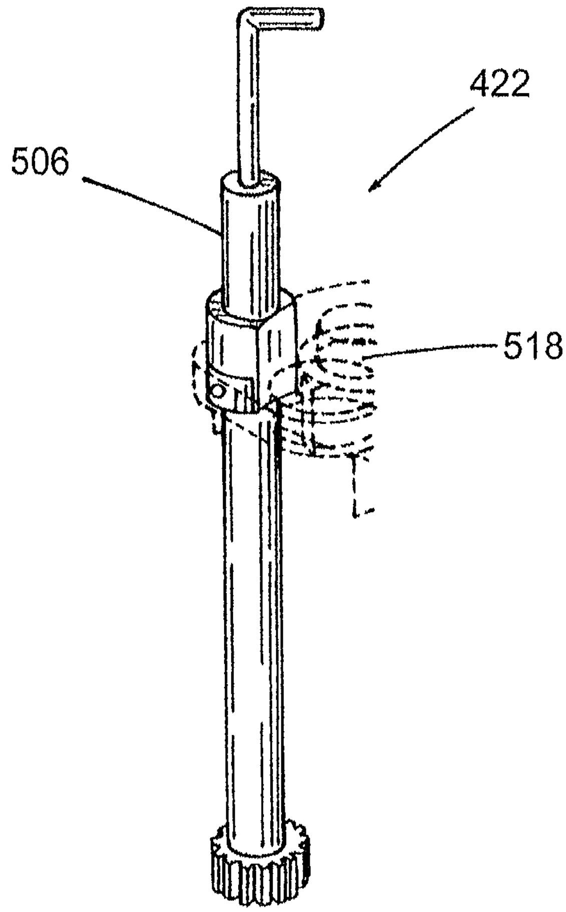

Fig. 22

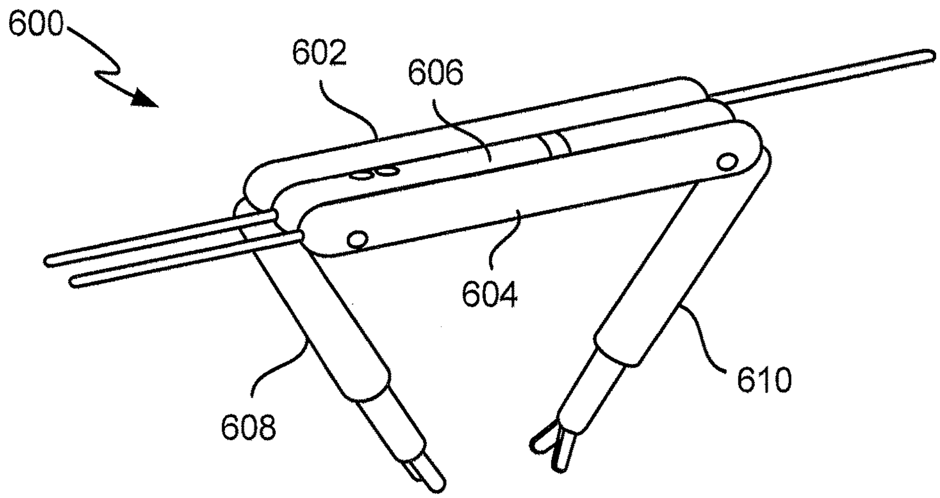

Fig. 23A

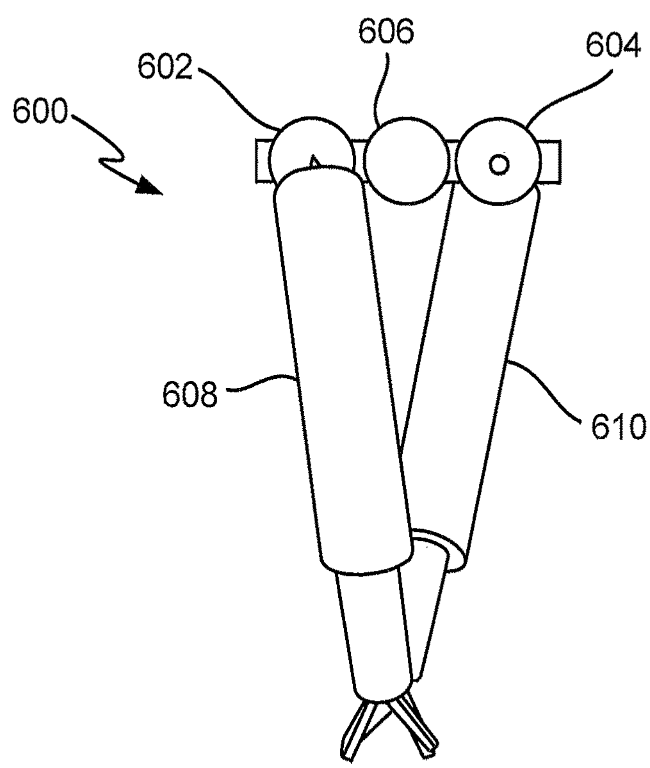

Fig. 23B

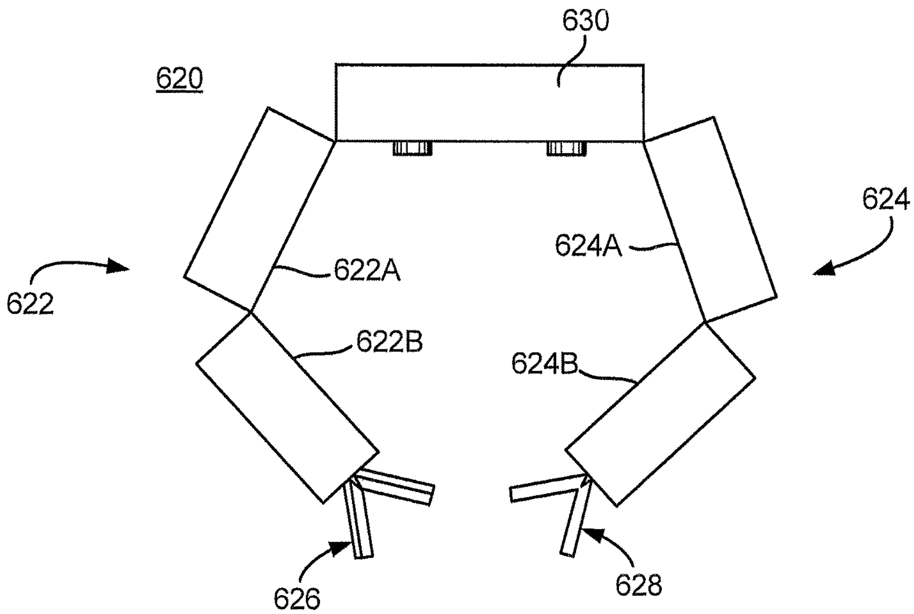

Fig. 24A

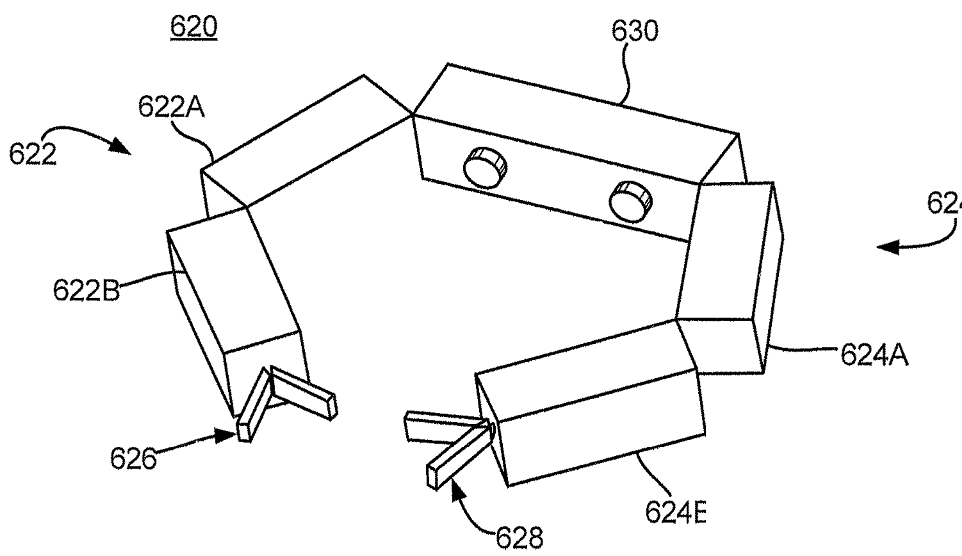

Fig. 24B

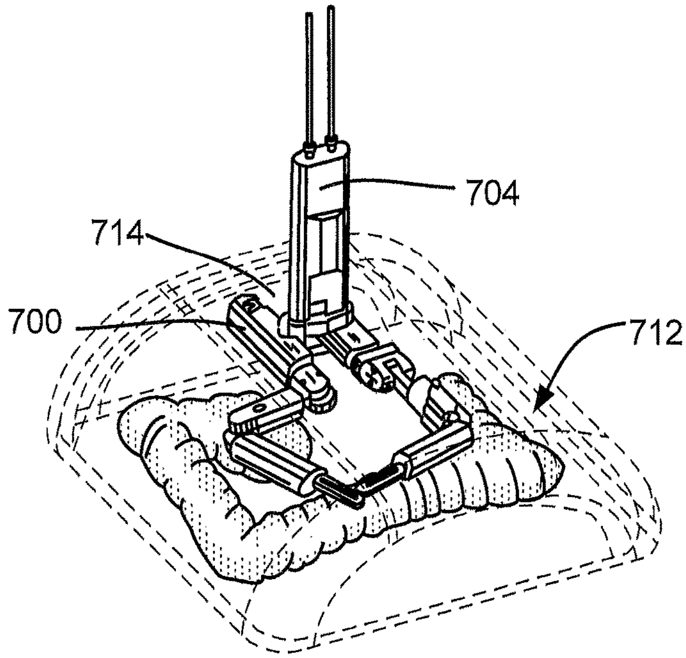

Fig. 25A

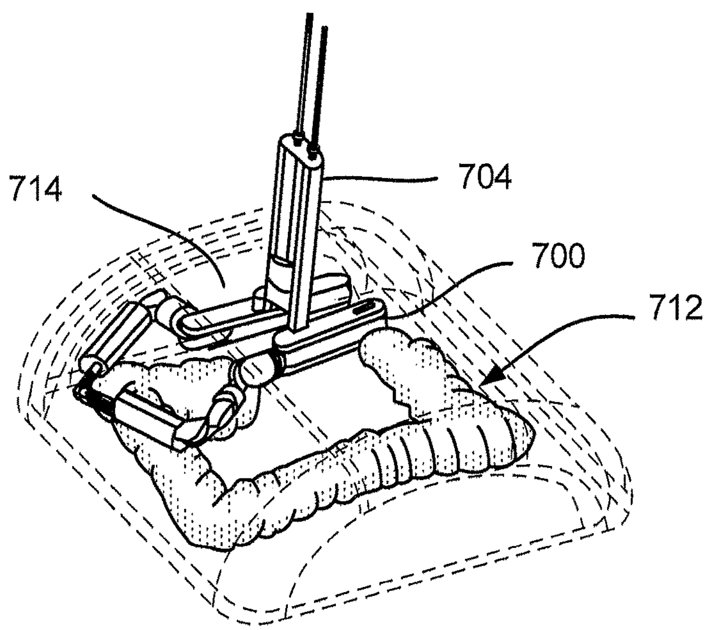

Fig. 25B

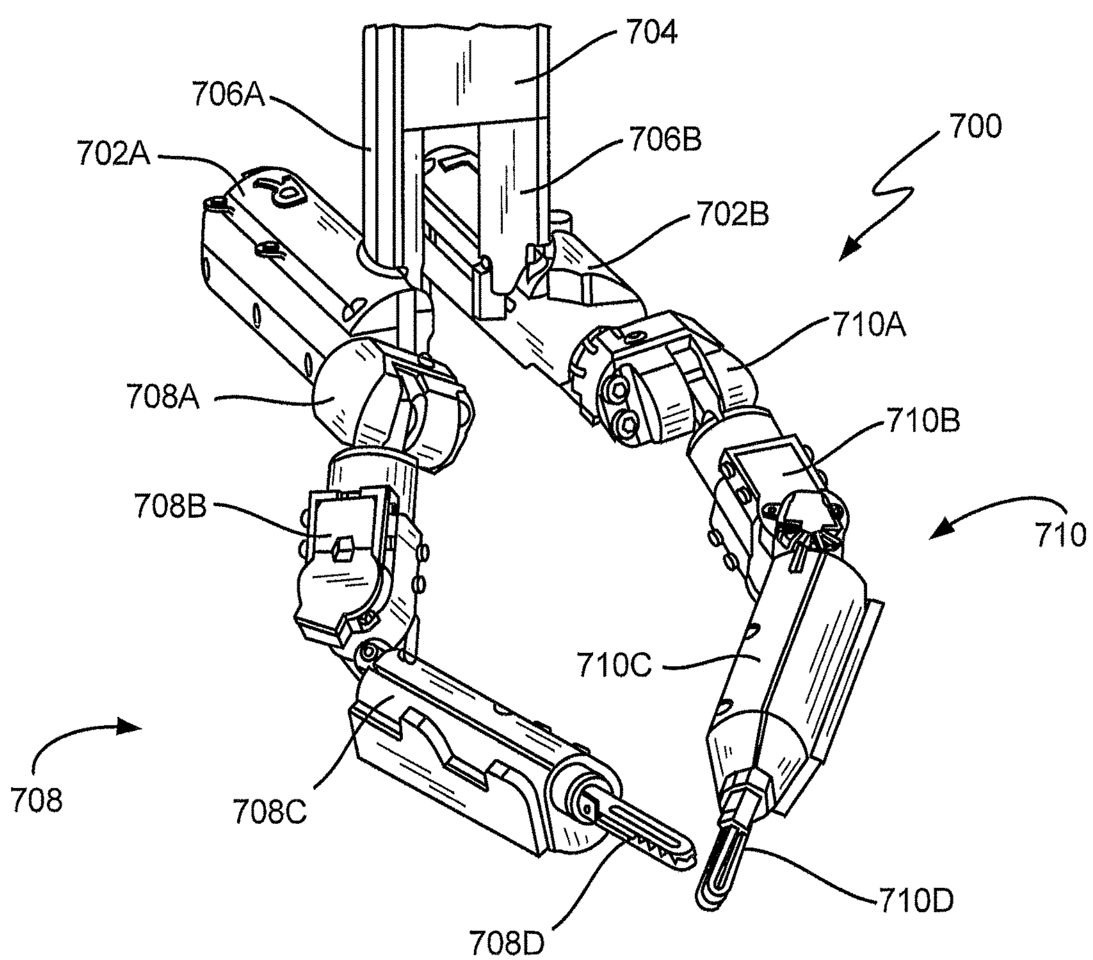
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Fig. 25C

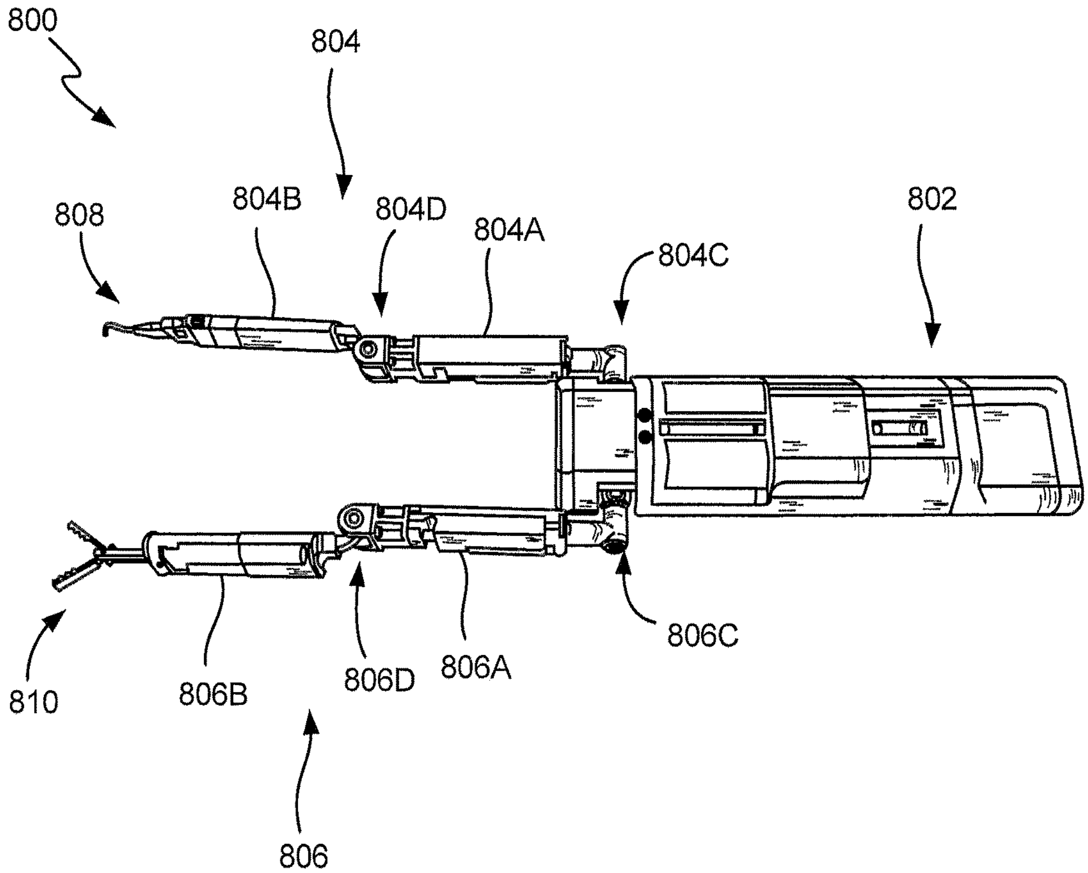
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Fig. 26A

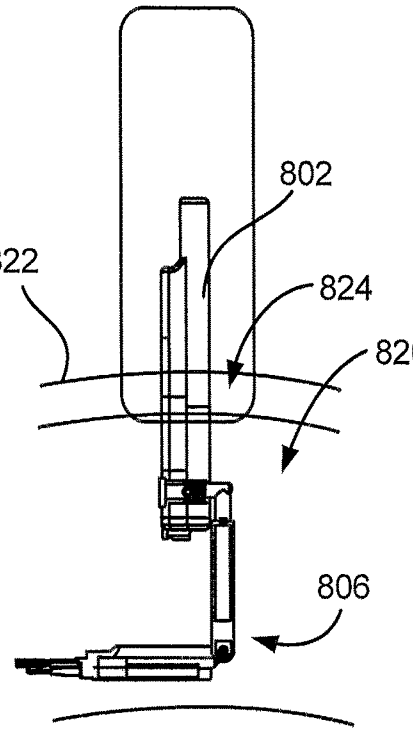

Fig. 26C

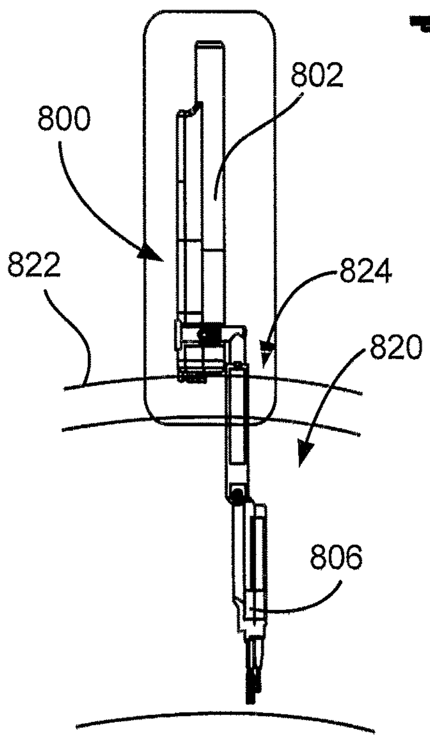

Fig. 26B

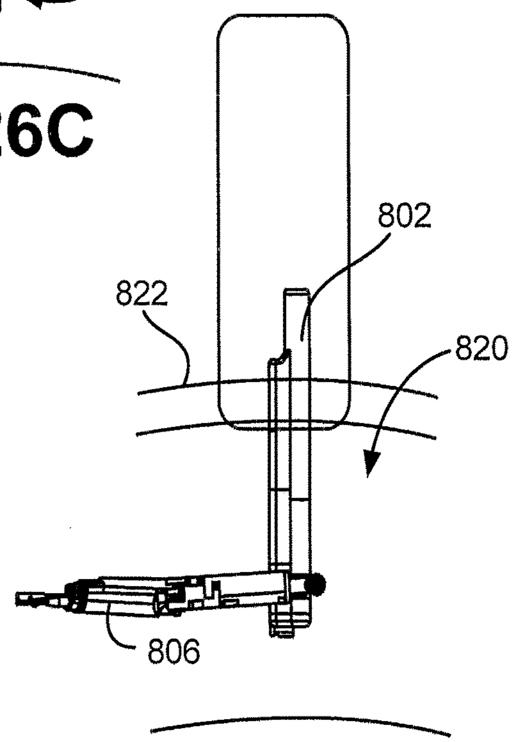

Fig. 26D

METHODS, SYSTEMS, AND DEVICES RELATING TO SURGICAL END EFFECTORS

CROSS-REFERENCE TO RELATED APPLICATION(S)

This application claims priority as a continuation application to U.S. application Ser. No. 13/493,725, filed on Jun. 11, 2012 is now U.S. Pat. No. 9,060,781, and entitled "Methods, Systems, and Devices Relating to Surgical End Effectors," which claims priority to U.S. Provisional Patent Application 61/495,487, filed Jun. 10, 2011 and entitled "Vessel Sealing Device for Robotic Devices," and to U.S. Provisional Patent Application 61/498,919, filed Jun. 20, 2011 and entitled "Dual End Effector Components and Related Devices, Systems, and Methods," all of which are hereby incorporated herein by reference in their entireties.

GOVERNMENT SUPPORT

This invention was made with government support under Grant No. W81XWH-09-2-0185, awarded by the Telemedicine and Advanced Technology Research Center within the Department of Defense and Grant No. NNX09A071A, awarded by the National Aeronautics and Space Administration Experimental Program to Stimulate Competitive Research. Accordingly, the United States government may have certain rights in the invention.

FIELD OF THE INVENTION

The embodiments disclosed herein relate to various medical device components and related components, including robotic and/or in vivo medical devices and related components. More specifically, certain embodiments include various medical device attachment and control components, often referred to as "end effectors" or "operational components." Certain end effector embodiments disclosed herein include vessel sealing and cutting devices, and, in particular, bipolar cautery devices having integrated cutting components. Other end effector embodiments disclosed herein include various dual end effector components, wherein such components have two or more end effectors. Further embodiments relate to systems and methods for operating the above components.

BACKGROUND OF THE INVENTION

Invasive surgical procedures are essential for addressing various medical conditions. When possible, minimally invasive procedures, such as laparoscopy, are preferred.

However, known minimally invasive technologies such as laparoscopy are limited in scope and complexity due in part to the need to remove and insert new surgical tools into the body cavity when changing surgical instruments due to the size of access ports. Known robotic systems such as the da Vino® Surgical System (available from Intuitive Surgical, Inc., located in Sunnyvale, Calif.) are also restricted by the access ports, the necessity for medical professionals to remove and insert new surgical tools into the abdominal cavity, as well as having the additional disadvantages of being very large, very expensive, unavailable in most hospitals, and having limited sensory and mobility capabilities.

There is a need in the art for improved surgical methods, systems, and devices.

BRIEF SUMMARY OF THE INVENTION

Discussed herein are various surgical end effectors—including certain cauterizing end effectors and certain dual end effectors—for use in surgical devices, including robotic in vivo devices.

In Example 1, an in vivo vessel sealing device comprises a device body and a bipolar vessel cautery component operably coupled to the device body. The device body has a cautery component actuation motor, a cutting component actuation motor, a jaw actuation motor, and a cautery component shaft disposed within the body and operably coupled to the jaw actuation motor. The cautery component has a stationary jaw coupled to a distal end of the cautery component shaft, a mobile jaw pivotally coupled to the distal end of the cautery component shaft, and a cutting component operably coupled to the cutting component actuation motor. In addition, the cautery component is operably coupled to the cautery component actuation motor.

Example 2 relates to the sealing device according to Example 1, wherein the cautery component is rotatable about an axis parallel with the shaft.

Example 3 relates to the sealing device according to Example 1, wherein the overall length of the device body is under about 3 inches.

Example 4 relates to the sealing device of Example 1, wherein the overall length of the cautery component is under about 1.5 inches.

Example 5 relates to the sealing device of Example 1, wherein the device is an end effector coupled to an arm of an in vivo robotic device.

Example 6 relates to an in vivo robotic device comprising a device body operably coupled to at least one arm, wherein the sealing device of Example 1 is operably coupled to the at least one arm.

In Example 7, a method of cauterizing tissue of a patient with an in vivo cautery device comprises positioning an in vivo cautery device near the tissue, positioning a cautery component rotationally in relation to the tissue with a cautery component actuation motor, and opening a mobile jaw with a jaw actuation motor and positioning the cautery component such that the tissue is positioned between the mobile and stationary jaws. The method further comprises closing the mobile jaw with a jaw actuation motor, applying an electrical current to the tissue via the mobile and stationary jaws, thereby cauterizing the tissue, and urging the cutting component in a distal direction with the cutting component actuation motor, thereby cutting the cauterized tissue positioned between the mobile and stationary jaws.

In Example 8, an operational component for an in vivo surgical device comprises an actuator housing comprising at least one actuator; and an end effector housing operably coupled to the actuator housing. The end effector housing comprises a first end effector rotationally coupled to the end effector housing and a second end effector rotationally coupled to the end effector housing.

While multiple embodiments are disclosed, still other embodiments of the present invention will become apparent to those skilled in the art from the following detailed description, which shows and describes illustrative embodiments of the invention. As will be realized, the invention is capable of modifications in various obvious aspects, all without departing from the spirit and scope of the present invention. Accordingly, the drawings and detailed description are to be regarded as illustrative in nature and not restrictive.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A is a perspective view of a vessel sealing device, according to one embodiment.

FIG. **1**B is a front view of a vessel sealing device, according to one embodiment.

FIG. **1**C is a side view of a vessel sealing device, according to one embodiment.

FIG. **2** is a side view of a vessel sealing device longitudinally sectioned to show component staging, according to one embodiment.

FIG. **3**A is a perspective view of a vessel sealing device with the exterior shown transparent to reveal inner components, according to one embodiment.

FIG. **3**B is a front view of a vessel sealing device with the exterior shown transparent to reveal inner components, according to one embodiment.

FIG. **4** is a side view of a vessel sealing device longitudinally sectioned to show inner components, according to one embodiment.

FIG. **5** is a perspective view of a vessel sealing device laterally sectioned to show inner components, according to one embodiment.

FIG. **6** is a view of a mobile jaw for a vessel sealing device in the closed position (top), partially open position (middle), and fully open position (bottom), according to one embodiment.

FIG. **7** is a side view of a mobile jaw (top) and an outer shell (bottom) for a vessel sealing device, according to one embodiment.

FIG. **8**A is a perspective top view of a medical device with a dual end effector component in a first orientation, according to one embodiment.

FIG. **8**B is a perspective side view of the device and component of FIG. **8**A in a first orientation.

FIG. **9**A is a perspective top view of the device and component of FIG. **8**A in a second orientation.

FIG. **9**B is a perspective side view of the device and component of FIG. **8**A in a second orientation.

FIGS. **10**A and **10**B are schematic representations of the bi-directional range of motion of the component of FIG. **8**A.

FIGS. **11**A and **11**B are perspective isometric views of the component of FIG. **8**A.

FIGS. **12**A and **12**B are perspective side views of the component of FIG. **8**A.

FIGS. **13**A and **13**B are perspective front views of the component of FIG. **8**A.

FIG. **14** is a perspective front view of the component of FIG. **8**A.

FIG. **15** is a perspective top view of the component of FIG. **8**A.

FIG. **16** is a perspective side view of the component of FIG. **8**A.

FIG. **17** is a perspective isometric view of the component of FIG. **8**A.

FIG. **18** is a perspective front view of the component of FIG. **8**A.

FIG. **19** is a perspective front view of the component of FIG. **8**A.

FIG. **20** is a perspective isometric view of the component of FIG. **8**A.

FIG. **21** is a perspective side view of the component of FIG. **8**A.

FIG. **22** is a perspective isometric view of the component of FIG. **8**A.

FIG. **23**A is a perspective view of a robotic surgical device, according to one embodiment.

FIG. **23**B is a side view of the robotic surgical device of FIG. **23**A.

FIG. **24**A is a front view of a robotic surgical device, according to another embodiment.

FIG. **24**B is a perspective view of the robotic surgical device of FIG. **24**A.

FIG. **25**A is a perspective view of a robotic surgical device positioned in a patient's peritoneal cavity, according to one embodiment.

FIG. **25**B is another perspective view of the robotic surgical device of FIG. **25**A.

FIG. **25**C is a perspective view of the robotic surgical device of FIG. **25**A.

FIG. **26**A is a front perspective view of a robotic surgical device, according to a further embodiment.

FIG. **26**B is a side view of the robotic surgical device of FIG. **26**A being inserted into a patient's body cavity, according to one embodiment.

FIG. **26**C is a side view of the robotic surgical device of FIG. **26**A being inserted into a patient's body cavity, according to one embodiment.

FIG. **26**D is a side view of the robotic surgical device of FIG. **26**A positioned a patient's body cavity, according to one embodiment.

DETAILED DESCRIPTION

The various systems and devices disclosed herein relate to devices for use in medical procedures and systems. More specifically, various embodiments relate to end effector devices that can be used in various procedural devices and systems. For example, certain embodiments relate to vessel sealing end effector devices, while other embodiments relate to dual end effector components incorporated into or used with robotic and/or in vivo medical devices. The term "dual end effector" as used herein shall mean an operational component having two or more interchangeable end effectors.

It is understood that the various embodiments of end effector devices or components disclosed herein can be incorporated into or used with any other known medical devices, systems and methods, including, but not limited to, robotic or in vivo devices as defined herein.

For example, the various embodiments disclosed herein can be incorporated into or used with any of the medical devices disclosed in U.S. application Ser. No. 11/932,441 (filed on Oct. 31, 2007 and entitled "Robot for Surgical Applications"), Ser. No. 11/695,944 (filed on Apr. 3, 2007 and entitled "Robot for Surgical Applications"), Ser. No. 11/947,097 (filed on Nov. 27, 2007 and entitled "Robotic Devices with Agent Delivery Components and Related Methods), Ser. No. 11/932,516 (filed on Oct. 31, 2007 and entitled "Robot for Surgical Applications"), Ser. No. 11/766,683 (filed on Jun. 21, 2007 and entitled "Magnetically Coupleable Robotic Devices and Related Methods"), Ser. No. 11/766,720 (filed on Jun. 21, 2007 and entitled "Magnetically Coupleable Surgical Robotic Devices and Related Methods"), Ser. No. 11/966,741 (filed on Dec. 28, 2007 and entitled "Methods, Systems, and Devices for Surgical Visualization and Device Manipulation"), Ser. No. 12/171,413 (filed on Jul. 11, 2008 and entitled "Methods and Systems of Actuation in Robotic Devices"), Ser. No. 12/192,663 (filed on Aug. 15, 2008 and entitled "Medical Inflation, Attachment, and Delivery Devices and Related Methods"), Ser. No. 12/192,779 (filed Aug. 15, 2008 and entitled "Modular and Cooperative Medical Devices and Related Systems"), Ser. No. 12/324,364 (filed Nov. 26, 2008 and entitled

"Multifunctional Operational Component for Robotic Devices"), 61/030,588 (filed on Feb. 22, 2008 and entitled Medical Devices having a Positionable Camera), Ser. No. 12/971,917 (filed on Dec. 17, 2010 and entitled "Modular and Cooperative Medical Devices and Related Systems and Methods"), 61/506,384 (filed on Jul. 11, 2011 and entitled "Robotic Surgical Devices, Systems, and Related Methods"), 61/542,543 (filed on Oct. 3, 2011 and entitled "Robotic Surgical Devices, Systems, and Related Methods"), 61/584,947 (filed on Jan. 10, 2012 and entitled "Methods, Systems, and Devices, for Surgical Access and Insertion"), and 61/640,879 (filed on May 1, 2012 and entitled "Single Site Robotic Device and Related Systems and Methods"), all of which are hereby incorporated herein by reference in their entireties.

In accordance with certain exemplary embodiments, any of the various embodiments disclosed herein can be incorporated into or used with a natural orifice transluminal endoscopic surgical device, such as a NOTES device. Those skilled in the art will appreciate and understand that various combinations of features are available including the features disclosed herein together with features known in the art.

Certain device implementations disclosed in the applications listed above can be positioned within a body cavity of a patient, including certain devices that can be positioned against or substantially adjacent to an interior cavity wall, and related systems. An "in vivo device" as used herein means any device that can be positioned, operated, or controlled at least in part by a user while being positioned within a body cavity of a patient, including any device that is positioned substantially against or adjacent to a wall of a body cavity of a patient, further including any such device that is internally actuated (having no external source of motive force), and additionally including any device that may be used laparoscopically or endoscopically during a surgical procedure. As used herein, the terms "robot," and "robotic device" shall refer to any device that can perform a task either automatically or in response to a command.

Further, the various end effector embodiments could be incorporated into various robotic medical device systems that are actuated externally, such as those available from Apollo Endosurgery, Inc., Hansen Medical, Inc., Intuitive Surgical, Inc., and other similar systems, such as any of the devices disclosed in the applications that are incorporated herein elsewhere in this application.

Certain embodiments disclosed herein relate to end effector devices for use in sealing vessels, including certain embodiments used in combination with any of the various procedural device embodiments described above. One such embodiment is a cautery device. FIGS. **1A-1C** depict one embodiment of a cautery device **10** having a proximal end **30** and a distal end **40**. In the cautery device **10** depicted in FIGS. **1A-1C**, the device **10** includes a body **20** with a bipolar cautery component **12** at the distal end **40**.

Known minimally-invasive in vivo cautery devices use a monopolar hook cautery component. In contrast, the embodiments disclosed herein provide a different device that cauterizes and cuts vessels with more precision and with reduced damage to the surrounding tissue.

As best shown in FIGS. **1A-1C**, the bipolar cautery component **12**, also termed a "cautery end effector" herein, includes a stationary jaw component **14**, a mobile jaw component **16** for clasping and cauterizing a vessel (e.g., a vein or artery), and a cutting component **18** for cutting the cauterized vessel, thus providing a three function end effector **12**. The stationary jaw component **14** and mobile jaw component **16** are structured like a pair of jaws, with the stationary jaw component **14** being configured to remain stationary during the cautery process, providing a substantially rigid and stable base to support a vessel. The mobile jaw component **16** is configured such that it can move in a jaw-like fashion in relation to the stationary jaw component **14** such that the mobile jaw component **16** can ultimately make contact with the vessel positioned between the stationary jaw component **14** and the mobile jaw component **16** to clasp the vessel between the jaws **14**, **16**.

As best shown in FIGS. **6** and **7**, according to one embodiment, the mobile jaw **16** additionally includes a pivot component **13** that that projects laterally from the proximal end of mobile jaw **16** and includes a receptacle **13*a*** for receiving a pin **13*b***. The pivot component **13** is generally peg- or wedge-shaped to fit through an opening in outer shell **15** and facilitates movement of mobile jaw **16** as described herein below. Stationary jaw **14** includes an opening **14*a*** configured to align with receptacle **13** and receive pin **13*b***.

Returning to FIGS. **1A-1C**, each of the fixed jaw component **14** and mobile jaw component **16** is connected to a source of electrical current (not shown) such that the jaws **14**, **16** function as bipolar electrodes, with one jaw functioning as a cathode and one jaw functioning as an anode when an electric current is applied. In certain implementations, the source for electrical current is a generator (not shown) that provides current separately from electricity powering the motors. In some embodiments, the generator is located outside of device **10** as a separate component. In use, the electricity flowing through the jaws **14**, **16** creates heat which cauterizes a vessel clasped between the jaws **14**, **16**. In some embodiments, the current is applied discretely by the operator by, for example, pressing a button or flipping a switch on the generator.

As best shown in FIG. **4**, the stationary jaw **14** of the bipolar cautery end effector **12** is attached to a shaft **32** that extends proximally from the stationary jaw **14** and is disposed within the body **20**. The cutting component **18** is positioned between the jaws **14**, **16** (as shown in FIGS. **1A-1C** and **4**) and extends through the shaft **32**. The shaft **32** has a slot **39** cut into either or both the top **34** or bottom **36** sides of the shaft **32** and extending longitudinally along part of the length of the shaft **32** to accommodate a pin **38** (as shown in FIG. **4**) that extends through the slot **39** and attaches to or extends through the cutting component **18** such that the pin is coupled to the cutting component. As such, the pin **38** and cutting component **18** can slide together along the slot **39** from a generally proximal first position to a more distal second position along with the cutting component **18**. In some embodiments as best shown in FIG. **5**, one or both of the stationary jaw **14** and mobile jaw **16** have a channel **26**, **28** within which the cutting component **18** moves from the first position to the second position.

In the embodiment illustrated in FIG. **4**, the cutting component **18** is substantially elongate and has a proximal end **24** and a distal end **25**. The cutting component **18** includes a cutting surface **22** at the distal end **25** such that when the cutting component **18** is moved from the generally proximal first position to the more distal second position, the cauterized vessel enclosed between the jaws **14**, **16** of the cautery device **10** is cut at the point of cautery.

For ease of description and understanding, the cautery device **10** as described herein has three sections **100**, **200**, **300**, as illustrated in FIG. **2**. In this embodiment, each section generally defines a plurality of components configured to control a function of the cautery device **10** within the body **20**. As such, the first section **100** controls the application of the electrical current to the jaws **14**, **16** as described above and rotation of the bipolar cautery end effector **12**. The second section **200** controls positioning of the cutting component **18**. Finally, the third section **300** controls opening and closing of the jaws **14**, **16** of the bipolar cautery end effector **12**. It is to be understood that while the illustrated embodiments utilize three sections, this identification and division of sections is provided solely for ease of description and understanding. It is also understood that the sections may be combined or split into more or fewer sections. For example, the first section **100** may be split into two sections separately controlling electrical current and end effector rotation.

According to some embodiments, the sections are configured and positioned such that the first section **100** is proximal to the bipolar cautery end effector **12**, while the third section **300** is located closest to the proximal end **30** of the device **10**, with the second section **200** being located between the first and third sections **100**, **300**. In some embodiments, the sections are configured and positioned such that the shape of the cautery device **10** becomes more slender toward the distal end. It is to be understood, however, that the sections may be configured or positioned in any manner suitable for proper function of the device, and may include any modifications that provide functional, aesthetic, and/or manufacturing advantages. Such advantages include, without limitation, visibility of the bipolar cautery end effector **12**, size reduction, reduced materials costs, and the like.

Power for the various functions of the device **10** as described herein is provided by the motors **102**, **202**, **302**, as best shown in FIGS. **4** and **5**. Electrical current for the motors **102**, **202**, **302** is provided by an electrical source (not shown). According to one implementation, the electrical source is positioned externally in relation to the device **10**. Alternatively, the electrical source can be positioned within the device. In some embodiments, the source of electricity for motors **102**, **202**, **302** also includes a control device (not shown) that includes components for controlling the motors **102**, **202**, **302** and/or sensing the status (e.g., position) of motors **102**, **202**, **302**. For example, the control device could be an external control device configured to be manipulated by a user. In some embodiments, the source of electric current for motors **102**, **202**, **302** is separate from the control device. In other embodiments, each motor **102**, **202**, **302**, is controlled and/or powered separately from one another. In some embodiments, the electricity for motors **102**, **202**, **302** is provided by the same electricity source as the current provided to jaws **14**, **16**.

As best shown in FIG. **5**, one or more of motors **102**, **202**, **302** have an encoder, e.g., **102***a*, **302***a*, (not shown for motor **202**), which is connected to the control device for receiving control instructions from the control device and providing data about the status of motors **102**, **202**, **302** to the control device. In some embodiments, one or more motors **102**, **202**, **302** also have a gear head, e.g., **102***b*, **302***b*, (not shown for motor **202**). The gear heads **102***b*, **302***b*, (not shown for motor **202**) can be fixed or, in some embodiments, removable and interchangeable to provide multiple gear ratios.

In accordance with one implementation, due to the electrical nature of the bipolar cautery end effector **12**, the drivetrain—including the first **100**, second **200**, and third **300** sections of the device—is electrically isolated from the motors **102**, **202**, **302** through the use of non-conductive gears driven by the motors **102**, **202**, **302**. In one embodiment, the non-conductive gears are made of nylon. Alternatively, the gears can be made of any known non-conductive material that can be used in gears. The non-conductive gears inhibit electrical current from flowing through the drive train to the jaws **14**, **16** and producing electrical interference that affects communication between the motors **102**, **202**, **302** and control device. In some embodiments, both conductive and non-conductive gears are used. For example, in one implementation, as best shown in FIGS. **4** and **5**, gears **106**, **208**, **306** are made of non-conductive material, while gears **104**, **206**, **308** are made of a conductive material. In accordance with another implementation, the effect of electrical interference can be reduced through the use of interference-reducing software and/or components in the control device or encoder **102***a*, **302***a* instead of, or in addition to, the use of non-conductive gears.

As best shown in FIGS. **3**A and **5**, the first section **100** of the cautery device **10** includes a first section motor **102** that is operatively coupled to the bipolar cautery end effector **12** to control rotation of the bipolar cautery end effector **12**. In some embodiments, the first section motor **102** is directly coupled to the bipolar cautery end effector **12** or can be indirectly coupled to the bipolar cautery end effector **12** by one or more coupling means. For example, in the embodiment illustrated in FIGS. **3**A and **3**B, the first section motor **102** is coupled to the bipolar cautery end effector **12** by a first gear **104** and a second gear **106**, the second gear **106** being attached to the shaft **32** of the bipolar cautery end effector **12** via metal coupler **108**, as best shown in FIG. **5**, such that rotational movement produced by the first section motor **102** is transferred to rotational movement of the bipolar cautery end effector **12** around axis A depicted in FIG. **3**A. In some embodiments, metal coupler **108** is coupled to the bipolar cautery end effector **12** via an outer shell **15**. As best shown in FIGS. **6** and **7**, outer shell **15** projects distally from the metal coupler **108** and includes an opening **15***a* through which pivot component **13** on mobile jaw **16** projects and translates rotational movement of coupler **108** to shaft **32**.

Second gear **106** can be fixed to the metal coupler **108** using, for example, an adhesive (e.g., UV cure glue). In some embodiments, the second gear **106** and the metal coupler **108** are configured such that the shape of each component prevents the second gear **106** from moving relative to the metal coupler **108** (i.e., non-circular geometry). For example, the metal coupler **108** can be generally square-shaped to fit into a generally square-shaped hole in the second gear **106**.

Returning to FIG. **4**, the first section **100** additionally includes components for applying electrical current to the jaws **14**, **16**. In this embodiment, the first section **100** includes an electrical connection **110** for the mobile jaw **16**. The electrical connection **110** is configured to allow sliding contact to a first slip ring **112**, which is connected to a source of electrical current (not shown) either directly or indirectly. Slip ring **112** is generally U-shaped or C-shaped such that it maintains contact with electrical connection **110** when electrical connection **110** rotates with shaft **36**. The use of slip ring **112** rather than a wire to provide electrical connection to connection **110** prevents twisting of wires about the drive train as connection **110** rotates. Mobile jaw **16** is electrically connected to connection **110** via a conductor, such as wire **13***c* shown in FIG. **7** or other appropriate conductor. Electrical connection **110** is electrically isolated from stationary jaw **14** by the inclusion of a non-conductive (e.g., plastic) ring **17** between the connection **110** and the stationary jaw **14**. The first section also includes a second slip ring **114** associated with the stationary jaw **14**, that functions similarly to the first slip ring **112** by maintaining electrical contact with shaft **36** during rotation. The use of slip rings **112**, **114** to separately provide current to jaws **16**, **14**, respectively, allows one jaw to function as a cathode and one jaw to function as an anode when an electric current is applied. In some embodiments, it may be desirable to include additional components or modifications to limit or focus electrical communication between jaws **14**, **16**.

The second section **200** in the embodiment shown in FIG. **4** includes a second section motor **202** that is operatively coupled to the cutting component **18** to control movement of the cutting component **18** from a first position to a second position along line of movement M. The second section motor **202** is coupled to a threaded collar **204** either directly or indirectly via a coupling means. In the embodiment illustrated in FIG. **4**, the coupling means for coupling the second section motor **202** to the threaded collar **204** includes a first gear **206** connecting the second section motor **202** to a second gear **208**, the second gear **208** being attached to the threaded collar **204** using, for example, an adhesive (e.g., UV cure glue) or non-circular geometry, as described above. An end of the pin **38** attached to or extending through the cutting component **18** is seated in a thread **212** of the threaded collar **204** such that rotational movement produced by the second section motor **202** is translated to lateral movement of the pin **38** along M and thereby the cutting component **18**. The second section is configured such that the movement of the cutting component **18** along M is a distance ranging from about 0.5 to about 1.0 inches in order to cut a vessel clasped between jaws **14**, **16**. Alternatively, the distance ranges from about 0.7 inches to about 1.0 inches. However, the distance can be adjusted as appropriate for the vessel size and specific configuration of the cautery device **10**. In one embodiment, the pivot component **13** of mobile jaw **16** includes an opening through which the cutting component **18** passes when moved. When not being used to cut a vessel, the cutting component **18** is retracted to a position proximal to the jaws **14**, **16** such that the mobile jaw **16** may be opened or closed.

The third section **300** illustrated in FIGS. **4** and **5** includes a third section motor **302** that is operatively coupled to mobile jaw **16** to control opening and closing of the jaws **14**, **16**. In some embodiments, the third section motor **302** is directly coupled to shaft **32** or can be indirectly coupled to shaft **32** by one or more coupling means. For example, in the embodiment illustrated in FIGS. **4** and **5**, the third section motor **302** is coupled to the shaft **32** by a first gear **308** and a second gear **306**, the second gear **306** being attached to collar **310** using, for example, an adhesive (e.g., UV cure glue) or non-circular geometry. In some embodiments, the shaft **32** and collar **310** are threaded such that rotation produced by motor **302** is translated to lateral movement of the shaft **32** along M and thereby the jaws **14**, **16** relative to outer shell **15**. As best seen in FIG. **6**, opening **15***a* restricts lateral movement of pivot component **13** of mobile jaw **16** along M relative to outer shell **15** such that lateral translation of shaft **32** along M causes mobile jaw **16** to open or close by pivoting around pin **13***b* via the pivot component **13** at opening **15***a*.

In an alternative embodiment, stationary jaw **14** can be replaced with a second mobile jaw. In this embodiment, the second mobile jaw is pivotably attached to shaft **32** and includes a pivot component similar to pivot component **13**. In this embodiment, outer shell **15** is configured to include a second opening similar to opening **15***a* that restricts lateral movement of the pivot component of the second mobile jaw such that the second mobile jaw is opened and closed via translation of shaft **32** along M in a manner similar to mobile jaw **16**.

The third section **300** can further include a means for detecting the thickness of a vessel clasped between the jaws **14**, **16**. Vessel thickness can be calculated, for example, based on the amount of lateral translation of shaft **32** along M required to close mobile jaw **16** or the position of mobile jaw **16** relative to stationary jaw **14**. In some embodiments, the position of mobile jaw **16** relative to stationary jaw **14** is determined for example, by measuring electrical impedance between jaws **14**, **16**.

As discussed above, the cautery device embodiments disclosed herein can be utilized in any type of medical device, including those devices in which a compact or smaller size is desirable, such as devices for procedures to be performed within a patient. In order to achieve a cautery device with appropriate dimensions for such use, the dimensions of components disclosed herein can be adjusted to control the overall size of the device. For example, in one implementation, the motors **102**, **202**, **302** can range in size from about 8 mm to about 15 mm, while the overall length of the body is kept under about 3 inches. In some embodiments, the overall length of the cautery component is kept under about 1.5 inches. In some embodiments, the height and/or width is kept under 2 inches. Alternatively, other dimensions can be used depending on size, weight, and/or visibility requirements.

In use, the cautery device **20** is positioned next to the target vessel using a complementary system or device as described elsewhere such as an articulating robotic arm. Next, the cautery device **20** operates in the following manner to cauterize the vessel. The first section motor **102** rotates the cautery end effector **12** to position the jaws **14**, **16** in an alignment with the vessel such that the jaws may enclose the vessel. The third section motor **302** actuates the mobile jaw **16** to open and the cautery end effector **12** is positioned such that the vessel is located between the jaws **14**, **16**. The third section motor **302** then actuates the mobile jaw **16** to close with the vessel disposed between the jaws **14**, **16** and the source of electrical current (not shown) applies an electric current to the vessel via the jaws **14**, **16**, thereby cauterizing it. The second section motor **202** drives the cutting component **18** toward the distal end of the cautery device **20** and thus pushes the cutting surface **22** through the vessel enclosed in the jaws **14**, **16**, thereby cutting the vessel.

FIGS. **8A-22** depict a dual end effector operational component **410** that can be incorporated into any one of a variety of medical devices as described above. In this embodiment, the dual end effector operational component **410** is positioned on the end of a robotic arm **412**. It is further understood that the robotic arm **412** can be part of any robotic medical device, such as an in vivo device. As best shown in FIGS. **8A-10**B, the arm **412** has two arm segments, including a first arm segment (or "upper arm") **412**A and a second arm segment (or "forearm") **412**B. The first arm segment **412**A is rotatably coupled with a torso motor housing **414** via a joint or hinge (not shown). The torso motor housing **414** houses a motor and actuation mechanism (not shown) to provide rotation of the first arm segment **412**A relative to the torso motor housing **414**. Further, the first arm segment **412**A is rotatably coupled to the second arm segment **412**B at joint **416**A, while the second arm segment **412**B is rotatably coupled to the dual end effector operational component **410** at joint **416**B.

In one embodiment, the dual end effector operational component **410** has an actuator housing **418** and an end effector housing **420**. The end effector housing **420** has two end effector elements **422**, **424**. In the embodiment depicted in FIGS. **8A-10**B, one end effector element is a cautery component **422** and the second end effector element is a grasper **424**. Alternatively, the end effector elements on the dual end effector operational component **410** can be any known end effectors for use with medical devices, such as, for example, forceps, needle drivers, scissors, Ligasure™, or knife components, to list a few.

As best shown in FIGS. **8**A and **8**B, in one embodiment, although both end effector elements **422**, **424** remain operable, the end effector housing **420** is oriented so that the grasper **424** is accessible to the subject tissue and can perform a medical procedure.

As best shown in FIGS. **9**A and **9**B, in another embodiment, although both end effector elements **422**, **424** remain operable, the end effector housing **420** is oriented so that the cautery component **422** is accessible to the subject tissue and can perform a medical procedure.

In one embodiment, both end effector elements **422**, **424** can rotate in relation to the end effector housing **420**. More specifically, as best shown in FIG. **9**A, the cautery component **422** is rotatable relative to the end effector housing **420** as shown by arrow AA around an axis indicated by line A. Further, the grasper **424** is rotatable relative to the end effector housing **420** as shown by arrow BB around an axis indicated by line B. According to one embodiment, the grasper **424** is also configured to move between an open configuration and a closed configuration (not shown). In an alternative embodiment (not shown), both end effector elements **422**, **424** can rotate relative to the end effector housing **420** and also can be configured to move between an open configuration and a closed configuration, depending on the type of end effectors. In another alternative embodiment, the two end effectors can be operably coupled to each other such that both end effectors can be configured to move between open and closed positions.

As best shown in FIG. **10**A, in one embodiment, the dual end effector operational component **410** can be rotated relative to the second arm segment **412**B via the joint **416**B and an actuation motor and gear system (not shown) contained within the second arm segment **412**B.

As best shown in FIG. **10**B, in one embodiment, the dual end effector operational component **410** and the second arm segment **412**B can be rotated relative to the first arm segment **412**A via the joint **416**A and an actuation motor and gear system (not shown) within the first arm segment **412**A.

As best shown in FIGS. **11**A-**12**B, within the dual end effector **410**, the forearm gear housing **426** contains an actuation motor **428** that is rigidly coupled to a driveshaft **430**. The driveshaft **430** is rigidly coupled to a rotational motor spur gear **432**. The rotational motor spur gear **432** is rotatably coupled to a rotational gear **434** that is rigidly coupled to the second arm segment (such as, for example, the second arm segment **412**B as shown in FIGS. **8**A-**10**B). Actuation of the actuation motor **428** causes rotation of the driveshaft **430** and the rotational motor spur gear **432**. Rotation of the rotational motor spur gear **432** causes rotation of the dual end effector operational component **410** relative to the second arm segment (such as second arm segment **412**B).

As best shown in FIGS. **13**A and **13**B, in one embodiment, the cautery component **422** has a proximal cautery housing **436** rigidly attached to a distal cautery tip **438**. In one embodiment, the wire (not shown) supplying electricity to the cautery tip **438** is enclosed in the cautery housing **436**. The wire runs proximally through the dual end effector operational component **410** and is coupled at a proximal end of the wire to a power source such as a standard electrocautery generator (not shown). In another embodiment, the power source could be located within the dual end effector operational component **410**. According to the implementation as shown, the grasper **424** has a proximal grasper housing **440** coupled to two grasping elements **442**, **444**.

As best shown in FIG. **13**B, in one embodiment, the cautery housing **436** is rigidly coupled to a cautery rotational gear **446** within the end effector housing **420**. Further, the grasper housing **440** is rigidly connected to the grasper rotational spur gear **448** within the end effector housing **420**.

As best shown in FIG. **14**, the cautery rotational gear **446** is rotatably coupled with a rotational motor spur gear **450**. The rotational motor spur gear **450** is rotatably actuated by a rotational motor **452** and a rotational motor gearhead **454** coupled to the motor **452**. Actuation of the rotational motor **452** and rotational motor gearhead **454** causes rotation of the rotational motor spur gear **450**, and thus the cautery rotational gear **446** and the cautery housing **436**. The cautery housing **436** is further coupled to two bearing elements **456**, **458** proximal to the cautery rotational gear **446**: a distal bearing **456** and a proximal bearing **458**, both of which support the cautery housing **436** and reduce rotational friction thereof. The cautery housing **436** and proximal bearing **458** are further coupled to a cautery housing preload nut **460** that limits translation of the cautery housing **436** and provides a preload or clamping force for the two bearing elements **456**, **458** to aid in reducing friction during rotation of the cautery housing **436** by holding the bearing elements **456**, **458** in place during rotation.

In one embodiment, the grasper rotational spur gear **448** is rotatably coupled with the rotational motor spur gear **450**. Actuation of the rotational motor **452** and rotational motor gearhead **454** causes rotation of the rotational motor spur gear **450**, and thus causes rotation of the grasper rotational spur gear **448** and the grasper housing **440** simultaneously with rotation of the cautery housing **436**.

In one embodiment, proximal to the grasper rotational spur gear **448**, the grasper housing **440** is coupled to two beveled washer elements—a distal beveled washer element **462** and a proximal beveled washer element **464**—that provide compliance for the grasper and prevent contact between moving parts during rotation of the grasper housing **440**. The grasper housing **440** is further coupled to two bearing elements—a distal bearing **466** and a proximal bearing **468**—that provide support for and reduce rotational friction of the grasper housing **440**. The grasper housing **440** is further coupled to a distal hex preload nut **470** that limits translation of the grasper housing **440** and provides a preload or clamping force for the bearings **466**, **468** to help reduce friction during rotation of the grasper housing **440** by holding the bearings **466**, **468** in place during rotation.

In one embodiment, an actuation motor **472** is rigidly coupled to an actuation motor housing **474** by two actuation motor mounting bolts **476**, **478**. The actuation motor mounting bolts **476**, **478** constrains the translation and rotation motion of the actuation motor **472** to the actuation motor housing **474**.

As best shown in FIG. **15**, in one embodiment, the actuation motor **472** is rigidly coupled to the actuation motor spur gear **480**. Actuation of the actuation motor **472** causes rotation of the actuation motor spur gear **480** and this rotation is translated to the driveshaft housing spur gear **482**.

As best shown in FIG. **16**, the driveshaft housing spur gear **482** is rigidly coupled to the driveshaft housing **484** which is, in turn, rotatably coupled to the grasper driveshaft **486**. Rotation of the driveshaft housing spur gear **482** via actuation of the actuation motor **472** and the actuation motor spur gear **480** therefore results in rotation of the driveshaft housing **484**. Rotation of the driveshaft housing **484** in turn causes translation of the grasper driveshaft **486**.

In one embodiment, rotation of the driveshaft housing **484** is aided by a proximal hex preload nut **488**, several beveled washer elements **490**, **492**, **494** and bearing elements **496**, **498**. The driveshaft housing **484** is further rigidly coupled to a driveshaft housing screw **500** that constrains translation of the driveshaft housing **484** to the proximal bearing **498**.

As best shown in FIG. **17**, a grasper rotational pin **502** is threaded through one side of the grasper housing **440**, through a hole in each of the grasping elements **442**, **444** and is rigidly coupled on the opposite side of the grasper housing **440**. As the grasper driveshaft **486** is translated via rotation of the driveshaft housing **484** (as best shown in FIG. **16**), a connector pin **504** that connects the grasper driveshaft **486** to the grasper elements **442**, **444** slides up and down in the grooves of the grasper elements **442**, **444**. This translation in turn causes the grasper elements **442**, **444** to open and close.

As best shown in FIGS. **18** and **19**, the cautery component **422** can extend and retract as necessary for operation and accessibility of the desired end effector element. As best shown in FIG. **18**, the cautery component **422** can be retracted through retraction of the retractable cautery shaft **506** during operation of the grasper **424** so that unwanted contact with tissue by the cautery component **422** can be avoided. As best shown in FIG. **19**, during operation of the cautery component **422**, the cautery component **422** can be extended beyond the proximal tip of the grasper **424** by extension of the retractable cautery shaft **506**.

As best shown in FIGS. **20** and **21**, the cautery component **422** is extended and retracted through rotation of the rotational motor spur gear **450**. The rotational motor spur gear **450** is rotatably coupled to the upper long cautery shaft **508**. The upper long cautery shaft **508** is rigidly coupled to the lower long cautery shaft **510** via a set screw **512**. The lower long cautery shaft **510** is supported by two bearing elements **514**, **516**. The lower long cautery shaft **510** is rotatably coupled to the retractable cautery shaft **506**.

As best shown in FIG. **22**, rotation of the lower long cautery shaft **510** (depicted in FIGS. **20** and **21**) causes the retractable cautery shaft **506** to retract or extend via external threading on the retractable cautery shaft **506** and internal threading on the threaded cautery energizing ring **518**. The external threading of the retractable cautery shaft **506** causes the retractable cautery shaft **506** to translate up and down when the lower long cautery shaft **510** (depicted in FIGS. **20** and **21**) is rotated. Power is supplied to the cautery component **422** via a wire (not shown) connected to the energizing ring **518**.

As discussed above, the various embodiments disclosed herein relate to end effector devices that can be incorporated into any of the medical devices, including robotic and/or in vivo device, disclosed in the various patents and applications incorporated by reference above. Further, as also discussed above, the various implementations can be positioned on the end of a robotic arm.

For example, any of the embodiments disclosed herein can be incorporated into the robotic device embodiments disclosed in U.S. Pat. No. 8,679,096 (which was incorporated herein above), including the devices depicted in FIGS. **23**A-**24**B. FIGS. **23**A and **23**B depict a combination or modular medical device **600** having three modular components **602**, **604**, **606** coupled or attached to each other. More specifically, the device **600** has two robotic arm modular components **602**, **604** and one robotic camera modular component **606** disposed between the other two components **602**, **604**. Each of the modular arm components **602**, **604** have arms **608**, **610**. FIGS. **24**A and **24**B depict a robotic device **620** according to a further embodiment in which the device **620** has two arms **622**, **624**, each having a first link **622**A, **624**A and a second link **622**B, **624**B. Each arm **622**, **624** also includes operational components **626**, **628** that can be the same or different from one another. In addition, the device **620** has a body **630** that can have lighting and/or camera components and is disposed between and coupled to both arms **622**, **624** as shown.

As another example, the various embodiments disclosed herein can also be incorporated into the robotic device embodiments disclosed in U.S. Application 61/506,384 (which was incorporated herein above), including the device shown in FIGS. **25**A-**25**C. FIG. **25**C depicts a robotic device **700** having a body **702** having two components **702**A, **702**B, wherein the body **702** is coupled to a support component **704** having a first support leg **706**A and a second support leg **706**B. Body component **702**A is coupled to arm **708**, and body component **702**B is coupled to arm **710**. Each of the arms **708**, **710** has a first joint **708**A, **710**A (each of which can also be referred to as a "shoulder joint") that is coupled to the body components **702**A, **702**B. Each first joint **708**A, **710**A is coupled to a first link **708**B, **710**B that is rotatably coupled to a second link **708**C, **710**C. In addition, each arm **708**, **710** also has an operational component **708**D, **710**D coupled to the second link **708**C, **710**C.

As best shown in FIGS. **25**A and **25**B, the support component **704** is configured to maintain the device **700** in the desired positioned within a cavity **712** within the patient. The support component **704**, which is coupled to the body **702**, is disposed through an orifice or any other kind of opening in the body cavity wall **714** such that the distal portion of the component **704** coupled to the body **702** is disposed within the body cavity **712** while the proximal portion is disposed outside the patient's body and can be attached to an external component (not shown) so as to provide stability or fixed positioning for the device **700**.

In a further example, the various embodiments disclosed herein can also be incorporated into the robotic device embodiments disclosed in U.S. Application 61/640,879 (which was incorporated herein above), including the device depicted in FIGS. **26**A-**26**D. FIG. **26**A depicts a robotic device **800** having a main body **802**, a left arm **804**, and a right arm **806**. Each of the arms **804**, **806** is comprised of two segments: an upper arm (or first link) **804**A, **806**A, and a forearm (or second link) **804**B, **806**B, thereby resulting in each arm **804**, **806** having a shoulder joint (or first joint) **804**C, **806**C and an elbow joint (or second joint) **804**D, **806**D. Each arm **804**, **806** also has an end effector **808**, **810**. As shown in FIGS. **26**B-**26**D, the device **800** can be positioned in or inserted into a cavity **820** of a patient such that, during a procedure, the arms **804**, **806** are disposed entirely within the body cavity **820** while the device body **802** is positioned through an incision **824** in the wall **822** of the cavity **820**.

Although the present invention has been described with reference to preferred embodiments, persons skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention.

What is claimed is:

1. An end effector for an in vivo device, the end effector comprising:

(a) an actuator housing comprising at least one actuator, wherein the actuator housing is operably coupleable to an arm of an in vivo robotic device, wherein the arm and the actuator housing are configured to be positioned entirely within a cavity of a patient; and

(b) an end effector housing operably coupled to the actuator housing, the end effector housing comprising:

(i) a first end effector rotationally coupled to the end effector housing such that the first end effector is rotatable around a first axis parallel to a longitudinal axis of the actuator housing; and

(ii) a second end effector rotationally coupled to the end effector housing such that the second end effector is rotatable in around a second axis parallel to the longitudinal axis of the actuator housing,

wherein the first and second axes are non-coaxial.

2. The end effector of claim **1**, wherein the first end effector is a cautery component and the second end effector is a grasper.

3. The end effector of claim **1**, further comprising:

(a) a first end effector rotational gear operably coupled to the first end effector; and

(b) a second end effector rotational gear operably coupled to the second end effector.

4. The end effector of claim **3**, further comprising a rotational drive gear operably coupled to the first and second end effector rotational gears.

5. The end effector of claim **4**, wherein the at least one actuator comprises a first end effector actuation motor operably coupled to the rotational drive gear, wherein actuation of the first end effector actuation motor causes rotation of the first and second end effectors.

6. The end effector of claim **1**, further comprising a retractable shaft operably coupled to the first end effector.

7. The end effector of claim **1**, wherein the second end effector is a grasper.

8. The end effector of claim **7**, further comprising a grasper driveshaft operably coupled to the grasper, wherein the at least one actuator comprises a second end effector actuation motor operably coupled to the grasper driveshaft.

9. The end effector of claim **8**, wherein the grasper driveshaft is configured to move axially between a proximal position and a distal position.

10. The end effector of claim **9**, wherein the second end effector actuation motor is configured to cause the grasper driveshaft to move axially, wherein the axial movement of the second end effector driveshaft between the proximal and distal positions causes the grasper to move between closed and open positions.

11. An end effector for an in vivo device, the end effector comprising:

(a) an actuator housing comprising at least one actuator, wherein the actuator housing is operably coupleable to an arm of an in vivo robotic device, wherein the arm and the actuator housing are configured to be positioned entirely within a cavity of a patient; and

(b) an end effector housing operably coupled to the actuator housing, the end effector housing comprising:

(i) a cautery component end effector rotationally coupled to the end effector housing such that the cautery component end effector is rotatable around a first axis parallel to a longitudinal axis of the actuator housing;

(ii) a cautery component rotational gear operably coupled to the cautery component end effector;

(iii) a grasper end effector rotationally coupled to the end effector housing such that the grasper end effector is rotatable around a second axis parallel to the longitudinal axis of the actuator housing; and

(iv) a grasper rotational gear operably coupled to the grasper end effector,

wherein the first and second axes are non-coaxial.

12. The end effector of claim **11**, further comprising a rotational drive gear operably coupled to the cautery component and grasper rotational gears.

13. The end effector of claim **12**, wherein the at least one actuator comprises a first end effector actuation motor operably coupled to the rotational drive gear, wherein actuation of the first end effector actuation motor causes rotation of the cautery component and grasper end effectors.

14. The end effector of claim **11**, further comprising a grasper driveshaft operably coupled to the grasper end effector, wherein the at least one actuator comprises a second end effector actuation motor operably coupled to the grasper driveshaft, wherein the grasper driveshaft is configured to move axially between a proximal position and a distal position.

15. The end effector of claim **14**, wherein the second end effector actuation motor is configured to cause the grasper driveshaft to move axially, wherein the axial movement of the grasper driveshaft between the proximal and distal positions causes the grasper end effector to move between closed and open positions.

16. An end effector for an in vivo device, the end effector comprising:

(a) an actuator housing comprising at least one actuator, wherein the actuator housing is operably coupleable to an arm of an in vivo robotic device, wherein the arm and the actuator housing are configured to be positioned entirely within a cavity of a patient; and

(b) an end effector housing operably coupled to the actuator housing, the end effector housing comprising:

(i) a first end effector comprising a retractable cautery component, the retractable cautery component operably coupled to the end effector housing such that the retractable cautery component comprises a retracted position and an extended position, wherein the first end effector is rotatable around a first axis parallel to a longitudinal axis of the actuator housing; and

(ii) a second end effector operably coupled to the end effector housing, wherein the second end effector is rotatable around a second axis parallel to the longitudinal axis of the actuator housing,

wherein the first and second axes are non-coaxial.

17. The end effector of claim **16**, further comprising a retractable cautery shaft operably coupled to the retractable cautery component.

18. The end effector of claim **17**, further comprising a drive shaft operably coupled to the retractable cautery shaft, whereby rotation of the drive shaft causes the retractable cautery shaft to move between the retracted and extended positions.

19. The end effector of claim **18**, wherein the drive shaft is operably coupled to a rotational driven gear.

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